june 1959
the
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of
radio
engineers

Proceedings of the IRE

in this issue

THE IRE ENTERS SPACE
RELATIVITY AND SPACE TRAVEL
MASER AMPLIFIER FOR RADIO ASTRONOMY

TANTALUM PRINTED CAPACITORS
DIVERSITY COMBINING TECHNIQUES
AVALANCHE TRANSISTOR PULSE CIRCUITS
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REGGIA-SPENCER PHASE SHIFTER
PHASE-LOCKED OSCILLATORS
TRANSACTIONS ABSTRACTS
ABSTRACTS AND REFERENCES

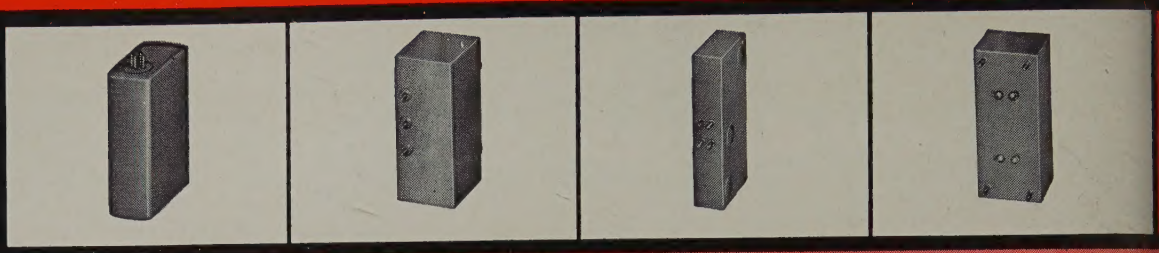
Masers in Radio Astronomy:
Page 1062

For Your Special Applications

The bulk of UTC production is on special units designed to specific customers' needs. Illustrated below are some typical units and some unusual units as manufactured for special applications. We would be pleased to advise and quote to your special requirements.

FILTERS

All types for frequencies from .1 cycle to 400 MC.



400 ⁓ telemetering, 3 db at ± 7.5%, 40 db at 230 and 700 ⁓, ⅝ x 1¼ x 2".

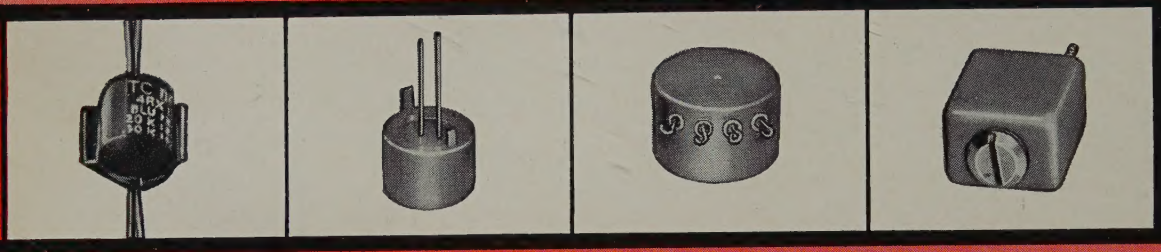
15 ⁓ BP filter, 20 db at 30 ⁓, 45 db at 100 ⁓, phase angle at CF less than 3° from —40 to + 100° C.

LP filter within 1 db to 49 KC, stable to .1 db from 0 to 85° C., 45 db at 55 KC.

LP filter less than .1 db 0 to 2.5 KC, 50 db beyond 3 KC.

HIGH Q COILS

Toroid, laminated, and cup structures from .1 cycle to 400 MC.



Tuned DO-T servo amplifier transformer, 400 ⁓ .5% distortion.

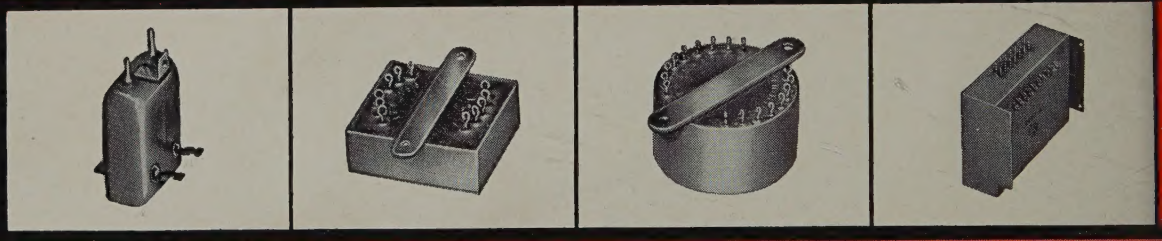
Toroid for printed circuit, Q of 90 at 15 KC.

Dual toroid, Q of 75 at 10 KC, and Q of 120 at 5 KC.

HVC tapped variable inductor for 3 KC oscillator.

SPECIALTIES

Saturable reactors, reference transformers, magnetic amplifiers, combined units.



RF saturable inductor for sweep from 17 MC to 21 MC.

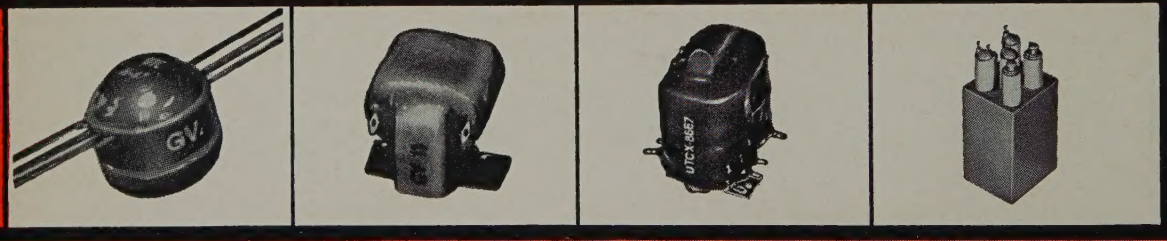
Voltage reference transformer .05% accuracy.

Multi-control magnetic amplifier for airborne servo.

Input, output, two tuned interstages, peaking network, and BP filter, all in one case.

PULSE TRANSFORMERS

From miniature blocking oscillator to 10 megawatt.



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Pulse current tansformer 100 Amp.

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VOLUME 47, NUMBER 6

June, 1959

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Proceedings of the IRE®

contents

Poles and Zeros 1045
Ferdinand Hamburger, Jr., Director at Large, 1959-1961 1046
Scanning the Issue 1047

PAPERS

IRE Enters Space, *L. V. Berkner* 1048
Relativity and Space Travel, *J. R. Pierce* 1053
A Maser Amplifier for Radio Astronomy at *X*-Band, *J. A. Giordmaine, L. E. Alsop, C. H. Mayer, and C. H. Townes* 1062
Tantalum Printed Capacitors, *R. W. Berry and D. J. Sloan* 1070
Linear Diversity Combining Techniques, *D. G. Brennan* 1075
Physical Principles of Avalanche Transistor Pulse Circuits, *D. J. Hamilton, J. F. Gibbons, and W. Shockley* 1102
Pulse Amplification Using Impact Ionization in Germanium, *M. C. Steele, L. Pensak, and R. D. Gold* 1109
The Transpolarizer: An Electrostatically Controlled Circuit Impedance with Stored Setting, *C. F. Pulvari* 1117
Geometric-Analytic Theory of Transition in Electrical Engineering, *E. Folke Bolinder* 1124
A Phenomenological Theory of the Reggia-Spencer Phase Shifter, *Jerald A. Weiss* 1130
A New Look at the Phase-Locked Oscillator, *Harold T. McAleer* 1137

CORRESPONDENCE

The Antipodal Reception of Sputnik III, *E. Woyk (E. Chvojková)* 1144
Apparent Correlation Between Tropopause Height and Long-Distance Transmission Loss at 490 mc, *D. R. Hay* 1144
Backward-Wave Oscillations in an Unloaded Waveguide, *Richard H. Pantell* 1146
The Use of Resolvers, *Carson K. H. Tsao* 1146
International Conference on Radio Wave Propagation, *T. J. Keary* 1147
A Topological Nonreciprocal Network Element, *A. W. Keen* 1148
X Circulator, *Shinichiro Yoshida* 1150
A Stability Characterization of the Reciprocal Linear Passive N Port, *D. Youla* 1150
Minimum Transmitter System Weight for Space Communications, *R. S. Davies and C. S. Weaver* 1151
A Log-Periodic Reflector Feed, *Dwight E. Isbell* 1152
A Torsional Magnetostrictive Delay Line, *A. Rothbart* 1153
Enhanced Correlator Output Through Optimum Delay-Line Processing, *H. Schimmel* 1154
Radiometer Circuits, *S. F. George and M. Graham* 1154
The Cause of Aurora Borealis, *Ralph R. Batcher* 1154
The Calculation of the Field in a Homogeneous Conductor with a Wavy Intercace, *James R. Wait* 1155
Phase Relationships at the Output of a Short Slot Hybrid Junction, *Robert D. Tompkins* 1156
Radio Reflections from Satellite-Produced Ionization, *C. R. Roberts, P. H. Kirchner, and D. W. Bray* 1156
WWV Standard Frequency Transmission, *National Bureau of Standards* 1157
The Need for Revision of Transistor Terminology and Notation, *B. E. Keiser and H. L. Armstrong* 1157
Semantics and Kirchhoff's Current Law, *B. J. Dasher* 1158
A Compact Antenna Switch for Scintillation Measurements, *W. D. Ryan* 1159
An Historical Note on Graphical Representation, *D. J. R. Stock and L. J. Koplan* 1159
Binary Multiplication in Digital Computers, *Abraham Green* 1159
Near-Zone Power Transmission Formulas, *Jean Robieux* 1161

published monthly by The Institute of Radio Engineers, Inc.

Proceedings of the IRE®

continued

REVIEWS

Scanning the TRANSACTIONS 1164
Report of the Secretary—1958 1165

Books:

"Electrical Engineering Materials," by A. J. Dekker, *Reviewed by Samuel Seely* 1169
"Liquid Scintillation Counting," ed. by C. G. Bell, Jr. and F. N. Hays, *Reviewed by W. A. Higonbotham* 1169
"The Theory and Design of Magnetic Amplifiers," by E. H. Frost-Smith, *Reviewed by H. F. Storm* 1170
"Progress in Metal Physics, Vol. 7, First Edition," ed by B. Chalmers, *Reviewed by Frank Herman* 1170
"A Facsimile Edition of George Green's Essay on Electricity and Magnetism," by Stig Ekelof, *Reviewed by S. A. Schelkunoff* 1170

ABSTRACTS

Abstracts of IRE TRANSACTIONS 1171
Abstracts and References 1176

IRE NEWS AND NOTES

Calendar of Coming Events 14A
Professional Group News 16A

Programs

URSI International Symposium on Electromagnetic Theory 18A
Third National Convention on Military Electronics 20A
IRE Committees and Representatives—1959 ..... 26A

DEPARTMENTS

Contributors 1161
IRE People 48A
Industrial Engineering Notes 6A
Meeting with Exhibits 8A
Membership 158A
News—New Products 46A
Positions Open 130A
Positions Wanted by Armed Forces Veterans 124A
Professional Group Meetings 114A
Section Meetings 146A
Advertising Index 200A

COVER

Columbia University and NRL scientists have substantially improved the performance of the radio telescope at the Naval Research Laboratory by equipping it with a maser pre-amplifier, mounted near the focus of the 50-foot reflector, as described on page 1062.

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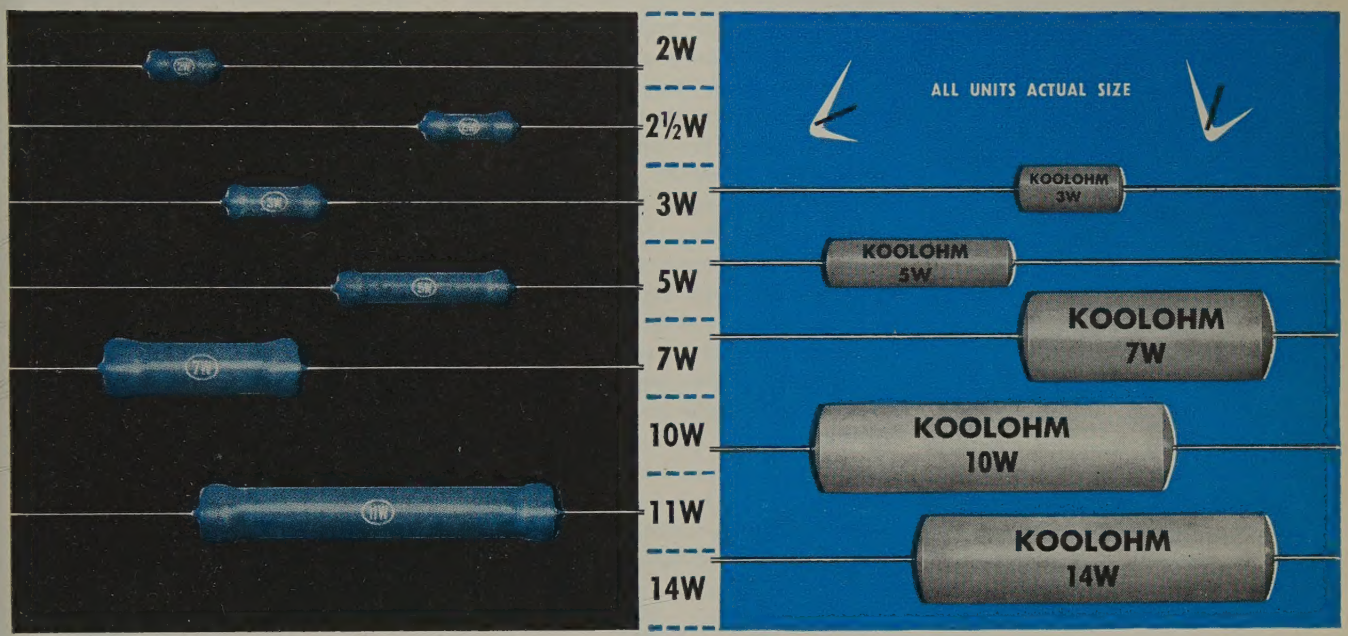

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Karle Packard's first two articles in this series on reliability demonstrated that the major factors in the unreliability of electronic equipment were interdependence, complexity and variability. The major methods of ensuring reliability are in this article.

The General Methods of Solving The Reliability Problem

Reliability of Parts

The problem of stability and resistance to environment begins with the smallest unit, the component part. In the case of mechanical parts they can usually be designed so that they will withstand the expected environment with an adequate margin of safety. Material strengths are well known and there is usually a reasonable choice of materials. Electrical parts on the other hand, are considerably more complicated than mechanical parts. They have not only the same, or similar, mechanical limitations, but also a varied assortment of electrical properties. The desired electrical properties usually conflict with the desired mechanical properties and one can seldom obtain a completely satisfactory compromise. Furthermore, the standard electrical part, the factor which has contributed so greatly to the advances in electrical engineering, has, at the same time, removed the control of part design from the hands of the engineer who uses it. The design of standard parts is, by nature, always at least one step behind the needs. Thus the standard part is a boon, not without drawbacks. The design engineer is relieved of some of the less glamorous aspects of engineering, but he must work with those parts available.

There are only three courses of action which the engineer can take with regard to the choice of electrical parts. These are:

a.) ascertain, through adequate testing, that a particular part is satisfactory.

b.) determine, through a simplified comparison test, which is the best available part.

c.) develop, or have a manufacturer develop, a part which is satisfactory. Methods a.) and c.) are complicated by the fact that it is usually difficult, and sometimes impossible, to define a "satisfactory" part. They are, furthermore, very expensive, usually requiring the testing of thousands of items over long periods of time and under a wide variety of environmental conditions. For this reason they are not usually economically justifiable. This leaves method b.) as the most practical and one which will at least result in equipment which is best within the state-of-the-art.

Having chosen suitable parts, it is then important that the equipment be packaged in such a way that deleterious effects of environment are minimized. This includes cooling, sealing and shock and vibration isolation.

Reliability of Circuits

Circuits are not directly affected by environment, but only through the effects on the parts making up the circuit. The stability of circuits may, therefore, be improved by designing them to be very tolerant of changes in part characteristics. A well-known example of this is the use of degenerative feedback. In addition, however, it should be borne in mind that any particular circuit with specific part values is only one of many possible combinations of similar parts, and it would be purely fortuitous if the first one chosen were the best. In general, it is possible to find a combination of part characteristics which will make the circuit least sensitive to variations in these characteristics.

Circuits should usually be as simple as possible, and if an old, well-tried circuit is adequate it should be used. It is sometimes possible, however, to make a circuit less critical,

with respect to part characteristics, by making it more complex. If the required trouble-free service life is long and the equipment relatively simple, then the added complexity would usually be worthwhile. If the equipment is quite complex (equipment life is limited by "accidental" failures) and adequate maintenance is possible, then the added complexity is not usually advisable. An exception to the latter statement may be made when the added parts are not essential to the operation of the circuit and their failure will not cause the circuit to fail.

An effective maintenance program, wherein incipient part failures are detected and these parts are replaced, will greatly improve equipment reliability. Such a program is related to circuit reliability in that failure detection methods can be established during circuit design.

Reliability of Higher-Order Structures

The reliability of sub-assemblies, assemblies, sub-systems, systems, etc., is a consideration somewhat like that for circuits. Analysis of these structures is usually straightforward since they are generally just series or parallel arrangements of lower-order structures and elementary probability calculus suffices. Such analysis is usually complicated, however, by the fact that unambiguous definitions of success and failure may be difficult to arrive at. Consideration of these problems is peculiar to the particular equipment concerned.

Redundancy

It has been mentioned previously that redundancy is one of the most powerful solutions to the reliability problem. There are two types of redundancy to be considered—series and parallel, these terms referring to the *logical arrangement* which often differs from the electrical arrangement. Series redundant elements are those wherein successful operation requires that *all* elements operate; they are redundant if successful operation could be obtained even if fewer elements were used. An example of this type is the use of two stages of amplification where one would suffice. This might be done to permit derating of each stage so as to improve the individual stage reliability. It would not be justifiable, however, unless the square of the reliability (less than unity) of each (identical) stage were greater than the reliability of a single, high-gain stage. The use of series redundancy is not often advisable and in any case the improvement in reliability so obtained is slight.

Parallel redundancy is that wherein successful operation may be achieved when only one of several redundant elements is operating. A simple example of this type is the use of a stand-by equipment. This type of redundancy may be used on a lower-level, such as the use of two d-c blocking capacitors (of a type which usually fail by short-circuiting) connected *in series electrically*. If one capacitor short-circuits, the other provides the blocking function (it is assumed that the increased time-constant can be tolerated). If a part can fail by either short-circuiting or open-circuiting, a rectangular matrix of such parts, connected in series-parallel, will provide parallel redundancy for both types of failure.

Parallel redundancy is one of the most potent factors in the survival of biological individuals and species, and in the stability of economic and political structures. Its use in engineering can provide considerable improvement in reliability. A word of caution should be inserted at this point, however, since the instrumentation of redundancy may bring unforeseen problems. In particular, when a decision device is required in order to choose between two or more redundant elements, the reliability of this device must be much higher than that of the redundant elements. This arrangement is known as "switch" redundancy. A "continuous" redundancy, such as the two capacitors mentioned above, requiring no decision device, is to be preferred whenever possible.

Economics of Solution

The reader who has absorbed the implications of the above discussion will realize that he faces a dilemma. The utmost in performance and the utmost in reliability are inherently incompatible and too great a sacrifice of either is disastrous. The attainment of a satisfactory compromise requires the introduction of another parameter, cost for example, in terms of which performance and reliability may be measured. The optimization of this parameter will then provide the best solution. No general rules can be stated for this optimization, except that techniques well known in operations research and game theory may be applied. It is the intent here to point out that a mature approach to the problem of equipment design will carefully balance performance and reliability and that judgment should be supported by logic.

The General Methods of solving the Reliability Problem is the third in a series of four articles written by Karle Packard. Part 4—The Language of Reliability—will appear on these pages in July, 1959.

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Industrial Engineering Notes*

Association Activities

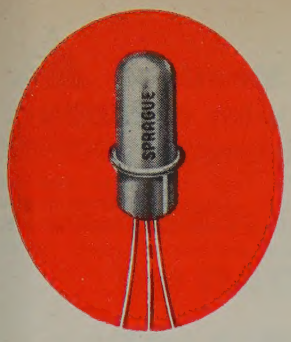
EIA has been accepted to membership in the Committee Consultative International Radio (CCIR) during the opening Plenary Assembly sessions at the Hotel Biltmore in Los Angeles. Official participation in this activity was approved by the EIA Board of Directors during its March 20 meeting in Washington. As a CCIR member, EIA will be kept fully informed of activities affecting the American electronics industry. The development and presentation of EIA positions on various questions under study will be coordinated by the International Standards Committee headed by Chairman Leon Podolsky. These comments will, in turn, be presented to the various U. S. Study Groups for consideration in the development of U. S. positions. . . . **EIA has been asked to bring to the attention of its members the recently issued 7th edition of the Directory of the American Council of Independent Laboratories, Inc., which is available without charge to company executives writing on company letterhead.** The Directory lists the Council's 75 members and their 50 branches in the chief metropolitan centers of the country. For a complimentary copy, write to: American Council of Independent Laboratories, Inc., 4302 East-West Highway, Washington 14, D.C.

Governmental and Legislative

The President has appointed a new Federal Council for Science and Technology to eliminate duplicatory research and development being conducted by various components of the federal government. The new Council, set up by executive order, will be an advisory body under the Chairmanship of Dr. James R. Killian, Jr., the President's Special Assistant for Science and Technology. . . . **The Army announced the development of an electric light slightly larger than a pinhead and a radio transmitter the size of an eraser on a pencil.** Both devices were developed by the Diamond Ordnance Fuze Laboratories and received awards for miniaturization achievement. The transmitter is used in ballistic studies. The device determines temperature of an artillery shell while in flight and instantaneously radios the information back to ground receivers. The lamp may be used in many types of dials such as those on control panels in missile research and electric computers. . . . **Effective July 1, 1961, envelopes will have to measure at least 3" by 5", according to a report to the House Post Office Committee by the U. S. Post Office Department.** This is so postal automation equipment can handle all mailings automatically. . . . **Sen. Warren G. Magnuson (D., Wash.), Chairman of the Senate Commerce Committee, said that five government agencies have approved the President's proposal to establish a 5-man Commission to study and report on U. S. telecommunication resources with special attention to the radio spectrum.** Legislation to accomplish this was introduced by Senator Magnuson at the request of the President (S. J. Res. 76). Chairman Magnuson said the State, Interior, and Commerce Departments, as well as the Office of Civil and Defense Mobilization and the Federal Communications Commission all have urged enactment of the resolution. Specifically, the resolution would require the Commission to study the allocation of radio frequencies between government and nongovernment users. Protests that the government users of the radio spectrum were using a greater part of the frequencies than justified, frequently have been heard in Congress and bills have been introduced to try to remedy the situation. The FCC suggested that the time for the Commission to make its study and report to the President be extended beyond one year, saying the Commission faced a tremendous job which would require a longer period to satisfactorily complete its work. It is suggested that the resolution be amended to make clear that "it only applied to the radio spectrum," the Senator said. "It also suggested that the Commission study the specific use the government and nongovernment users make of that part of the radio spectrum allotted to each," he said. Senator Magnuson said he hoped the Commission would be able to start on the proposal at an early date. . . . **"Our program for the next few years is solidly set, subject only to the provision of necessary funds by the Congress," Dr. T. Keith Glennan told a gathering in Cleveland.** The National Aeronautics and Space Administrator said, "Beyond that period our planning takes us into the preliminary stages of orbiting laboratories, lunar landings (both unmanned and manned), the development of systems components for meteorological and weather forecasting service, the development of a prototype of a global communications system and many other equally exciting activities." To accomplish these programs and plans, he said, "we must develop improved tracking and data acquisition techniques and equipment and must install additional stations around the world; we must develop guidance and control systems of greater accuracy and reliability than those presently available to us; we must recognize and prepare for increasing demand

(Continued on page 176A)

* The data on which these NOTES are based were selected by permission from *Weekly Reports*, issues of March 23, April 6, 13, and 20, published by the Electronic Industries Association whose helpfulness is gratefully acknowledged.



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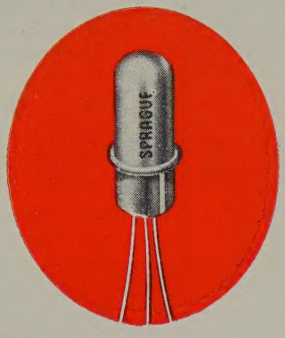

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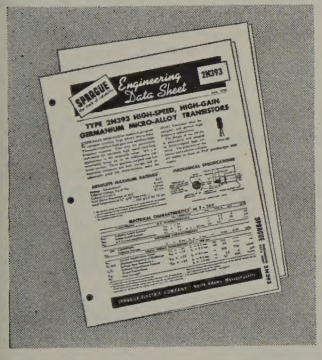

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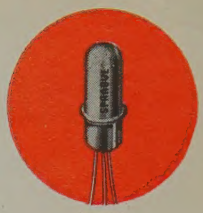

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SB MIL GENERAL PURPOSE
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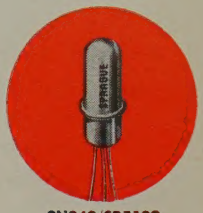


2N240/SB5122
FOR COMPUTER SWITCHING

2N344/SB101
FOR MEDIUM GAIN AMPLIFIERS

2N345/SB102
FOR HIGH GAIN AMPLIFIERS

2N246/SB103
FOR HIGH FREQUENCY OSCILLATORS

2N501
MADT FOR ULTRA-HIGH SPEED SWITCHING

SPRAGUE COMPONENTS:

TRANSISTORS • RESISTORS • MAGNETIC COMPONENTS • CAPACITORS • INTERFERENCE FILTERS • PULSE NETWORKS • HIGH TEMPERATURE MAGNET WIRE • CERAMIC-BASE PRINTED NETWORKS • PACKAGED COMPONENT ASSEMBLIES

SPRAGUE®
THE MARK OF RELIABILITY

NEW TRANSPAC®

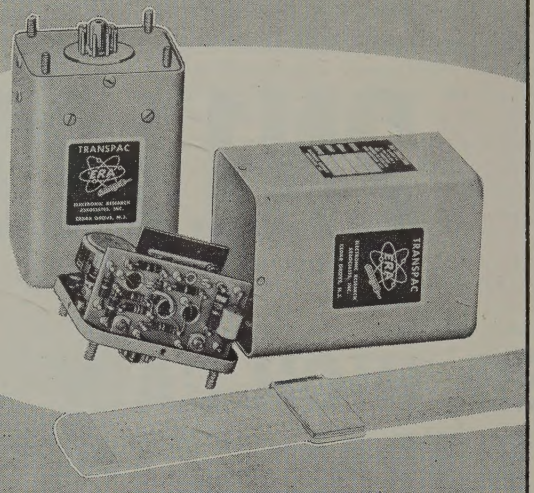
Miniaturized

SOLID STATE POWER PACKS

New Short-Circuit and Transient-Proof Circuitry . . .

FEATURES:

- Closely Regulated
- Low Ripple Content
- Advanced Thermal Design
- Short-Circuit Proof . . . automatic recovery
- Improved Circuitry and Transistor Types
- Thermal Transistor Stud Temperature Monitor and Automatic Cut-Off
- No Increase In Size or Weight
- No Increase In Price



ERA's transistorized *Transpacs* feature advanced circuit designs and improved technical specifications. New features include the incorporation of a special current limiter and protective circuitry. The current flow is monitored and in the event the load current exceeds a designated value, the current limiter reverses the control biases and prevents additional current from flowing. Also included in these units is a thermostatic device which registers transistor stud temperatures. In the event these temperatures become excessive, the thermostatic unit opens the circuit and thus prevents thermal run-away or damage to the unit or external circuit.

Wired into circuits like other components, *Transpacs* supply a rugged, reliable source of DC power for all types of miniature or standard size electronic devices.

®Reg. U.S. Pat. Off.

STANDARD MODELS

Input 105-125 VAC, 60 or 400 cps. Input regulation better than ±0.1%. Output regulation better than ±0.1%. Ripple less than 0.05%. All semi-conductor designs.

CASE SIZES: (WxDxH inch.)
D-2⅝x3 1/16x4¼
C-2⅜x2¾x3 1/16

**Prices FOB Cedar Grove. Subject to change without notice

Models listed are stock units. Special designs also available to customers specifications. Write for literature and quotations.

FIXED VOLTAGE TYPES

Model No.	Output Volts	Current Ma-Max	Case Size * 60 Cps	Case Size * 400 Cps	Net Price ** 60 Cps	Net Price ** 400 Cps
TR5	5	0-200	D	C	$ 70.00	$ 95.00
TR10	10	0-200	D	C	70.00	95.00
TR20	20	0-200	D	C	70.00	95.00
TR30	30	0-150	D	C	70.00	95.00
TR40	40	0-150	D	C	70.00	95.00
TR50	50	0-150	D	C	70.00	95.00

ADJUSTABLE VOLTAGE TYPES

Model No.	Voltage Range	Output MA	Case Size * 60 Cps	Case Size * 400 Cps	Net Price ** 60 Cps	Net Price ** 400 Cps
TR5A	5-10	0-200	D	C	$ 80.00	$105.00
TR10A	10-20	0-200	D	C	80.00	105.00
TR20A	20-30	0-150	D	C	80.00	105.00
TR30A	30-40	0-150	D	C	80.00	105.00
TR40A	40-50	0-150	D	C	80.00	105.00
TR50A	50-55	0-150	D	C	80.00	105.00

*400 cps units designated by prefix "F" (ie, TR5F, etc.)

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67 Factory Pl., Cedar Grove, N. J. CEnter 9-3000 TWX NJ1144
SUBSIDIARIES
Era Electric Corporation • Nutley, N. J. Era Pacific Inc. • Santa Monica, Cal.

Meetings with Exhibits

● As a service both to Members and the industry, we will endeavor to record in this column each month those meetings of IRE, its sections and professional groups which include exhibits.

Δ

June 24-28, 1959

International Conference on Medical Electronics, UNESCO House, Paris, France.

Exhibits: Mr. Carl Berkley, Rockefeller Institute for Medical Research, 66th St. & York Ave., New York 21, N.Y.

June 29-July 1, 1959

Third National Convention on Military Electronics, Sheraton-Park Hotel, Washington, D.C.

Exhibits: Mr. L. David Whitelock, Bu-Ship. Electronics Div., Dept. of Navy, Washington 25, D.C.

August 18-21, 1959

WESCON, Western Electronic Show and Convention, Cow Palace, San Francisco, Calif.

Exhibits: Mr. Don Larson, WESCON, 1435 La Cienega Blvd., Los Angeles, Calif.

September 23-25, 1959

Special Technical Conference on Non-Linear Magnetics and Magnetic Amplifiers, Shoreham Hotel, Washington, D.C.

Exhibits: Mr. J. L. Whitlock, 6044 Ninth St. N., Arlington 5, Va.

September 28-30, 1959

National Symposium on Telemetering, Civic Auditorium & Whitcomb Hotel, San Francisco, Calif.

Exhibits: Mr. Robert A. Grimm, Dymec, Inc., 395 Page Mill Road, Palo Alto, Calif.

October 5-7, 1959

Fifth National Communications Symposium, Hotel Utica, Utica, N.Y.

Exhibits: Mr. E. William Morris, 224 Fairway Drive, New Hartford, N.Y.

October 7-9, 1959

IRE Canadian Convention, Exhibition Park, Toronto, Ont., Canada

Exhibits: Mr. F. G. Heath, IRE Canadian Convention, 1819 Yonge St., Toronto 7, Ont., Canada.

October 12-14, 1959

National Electronics Conference, Hotel Sherman, Chicago, Ill.

Exhibits: Mr. Robert E. Bard, General Radio Co., 6605 W. North Ave., Oak Park, Ill.

October 26-28, 1959

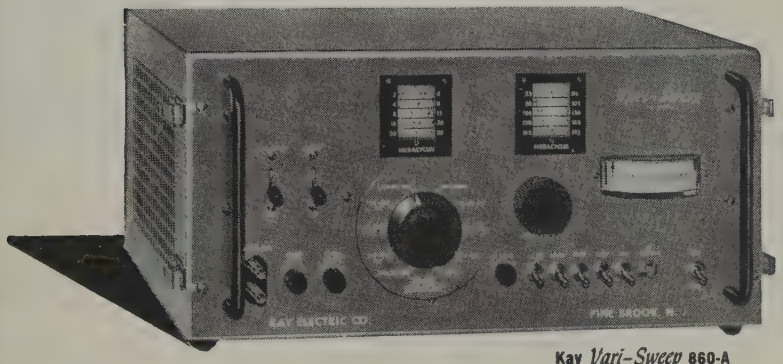
East Coast Aeronautical & Navigational Electronics Conference, Lord Baltimore Hotel & 7th Regiment Armory, Baltimore, Md.

Exhibits: Mr. R. L. Pigeon, Westinghouse Electric Corp., Air Arm Div., P.O. Box 746, Baltimore, Md.

(Continued on page 10A)

SWEEPING OSCILLATORS for RADAR and TELEMETERING IF's, 1-3,800 mc by

KAY ELECTRIC



Kay *Vari-Sweep* 860-A

The Kay sweeping oscillators are a line of high level lab and field test instruments designed for the alignment of radar, and telemetering IF strips from 1 to 3,800 mc. The line offers a wide choice of precision-built units which are simple to operate, highly stable, and extremely flexible.

- **Wide Range, Wide Sweep**
- **High Output**
- **Fundamental Frequency**
- **Constant Output (Fast-Acting AGC)**
- **Continuously Variable Centers**
- **Fixed, Crystal-Controlled Markers**
- **All Electronic Operation**

Instrument	Cat. No.	Range	Sweep Width	RF Output	Markers	Price†
Vari-Sweep	860-A	2-220 mc (center)	Contin. Variable to 60% center freq. below 50 mc; 30 mc plus, above 50 mc.	1.0 V rms AGC'd, 70 ohms	None	$745.
Vari-Sweep Model IF	866-A*	4-120 mc (center)		1.0 V rms AGC'd, 70 ohms	11 Fixed Crystals 1 Variable. Direct reading dial	$985.
Vari-Sweep Model Radar	865-A*	10-145 mc (center)		1.0 V rms AGC'd, 70 ohms	11 Fixed Crystals 1 Variable. Direct reading dial	$985.
Vari-Sweep Model 400	867-A	15-470 mc in 10 bands	Same as above to 400 mc; 20 mc max. above 400 mc.	1.0 V rms into 70 ohms to 220 mc; 0.5 V rms to 470 mc; all AGC'd	None	$795.
Mega-Sweep	110-A**	50 kc-950 mc	50 kc-40 mc	100 mv at 50 ohms	None	$545.
Kada-Sweep	380-A*	2 Switched bands 20-40 mc; 50-70 mc	2 Switched bands, Wide 20 mc, Nar. 3 mc	250 mv rms, 70 ohms	9 Fixed Crystals	$425. (with 4 crystals)
Magna-Sweep	3500	5-1000 mc 2200-3800 mc	Full range of swept band	Low band: 0.1 V rms into 50 ohms: High: 1.5 V into 50 ohms	±0.1% accurate direct reading digital wavemeter	$4,950.

**Other Mega-Sweeps to 1200 mc; and with Markers.

*Wider sweep widths, additional crystal markers available on special order.

† All prices F.O.B. Pine Brook, N. J.

Write for New Kay Catalog

KAY ELECTRIC COMPANY

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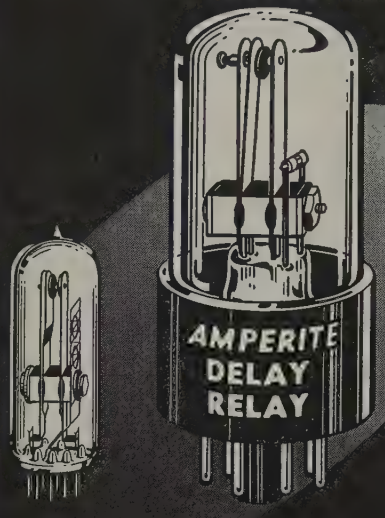
AMPERITE
PREFERRED

by design engineers—because they're
MOST COMPACT • SIMPLEST • MOST ECONOMICAL
HERMETICALLY SEALED



Thermostatic DELAY RELAYS

2 to 180 Seconds

Actuated by a heater, they operate on A.C., D.C., or Pulsating Current.

Hermetically sealed. Not affected by altitude, moisture, or climate changes.

SPST only—normally open or closed.

Compensated for ambient temperature changes from —55° to +70° C. Heaters consume approximately 2 W. and may be operated continuously. The units are **rugged, explosion-proof, long-lived,** and—**inexpensive!**

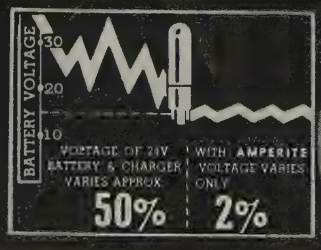
TYPES: Standard Radio Octal, and 9-Pin Miniature . . . **List Price, $4.00.** Standard Delays

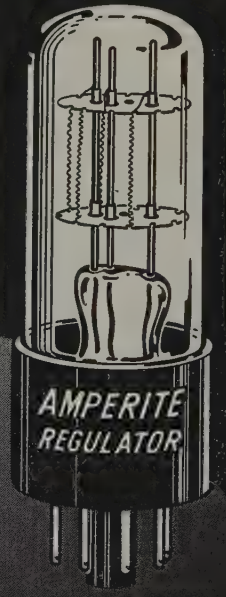
Also — **Amperite Differential Relays:** Used for automatic overload, under-voltage or under-current protection.

PROBLEM? Send for Bulletin No. TR-81

BALLAST REGULATORS

Amperite Regulators are designed to keep the current in a circuit **automatically regulated** at a definite value (for example, 0.5 amp.) . . . For currents of 60 ma. to 5 amps. Operate on A.C., D.C., or Pulsating Current.





Hermetically sealed, they are not affected by changes in altitude, ambient temperature (—55 to +90° C.), or humidity . . . Rugged, light, compact, most inexpensive . . . . . **List Price, $3.00.**

Write for 4-page Technical Bulletin No. AB-51

AMPERITE CO. Inc., 561 Broadway, New York 12, N. Y.
Telephone: CAnal 6-1446
In Canada: Atlas Radio Corp., Ltd., 50 Wingold Ave., Toronto 10

Meetings with Exhibits

(Continued from page 8A)

November 3-5, 1959

MAECON, Mid-America Electronics Convention, Municipal Auditorium, Kansas City, Mo.

Exhibits: Mr. John V. Parks, Bendix Aviation Corp., P.O. Box 1159, Kansas City 41, Mo.

November 9-11, 1959

Fourth Instrumentation Conference, Atlanta, Ga.

Exhibits: Dr. B. J. Dasher, School of E.E., Georgia Institute of Technology, Atlanta 13, Ga.

November 10-12, 1959

Twelfth Annual Electrical Techniques in Medicine and Biology Conference, Sheraton Hotel, Philadelphia, Pa.

Exhibits: Mr. Lewis Winner, 152 West 42nd St., New York 36, N.Y.

November 16-20, 1959

Conference on Magnetism & Magnetic Materials, Detroit, Mich.

Exhibits: Mr. L. J. Giacoletto, Ford Motor Company, Scientific Laboratory, Box 2053, Dearborn, Mich.

November 17-19, 1959

Northeast Electronics Research and Engineering Meeting (NEREM), Boston Commonwealth Armory, Boston, Mass.

Exhibits: Miss Shirley Whitcher, IRE Boston Office, 73 Tremont Street, Boston, Mass.

December 1-3, 1959

Eastern Joint Computer Conference, Hotel Statler, Boston, Mass.

Exhibits: Dr. Harrison W. Fuller, Laboratory for Electronics, 75 Pitt St., Boston 14, Mass.

December 3-4, 1959

PGVC Annual Meeting, Colonial Inn & Desert Ranch, St. Petersburg, Fla.

Exhibits: Mr. A. W Sullivan, Minneapolis-Honeywell Regulator Co., 13350 U. S. 19, St. Petersburg, Fla.

March 21-24, 1960

Radio Engineering Show and IRE National Convention, Waldorf-Astoria Hotel and New York Coliseum, New York, N.Y.

Exhibits: Mr. William C. Copp, Institute of Radio Enginers, 72 West 45th St., New York 36, N.Y.

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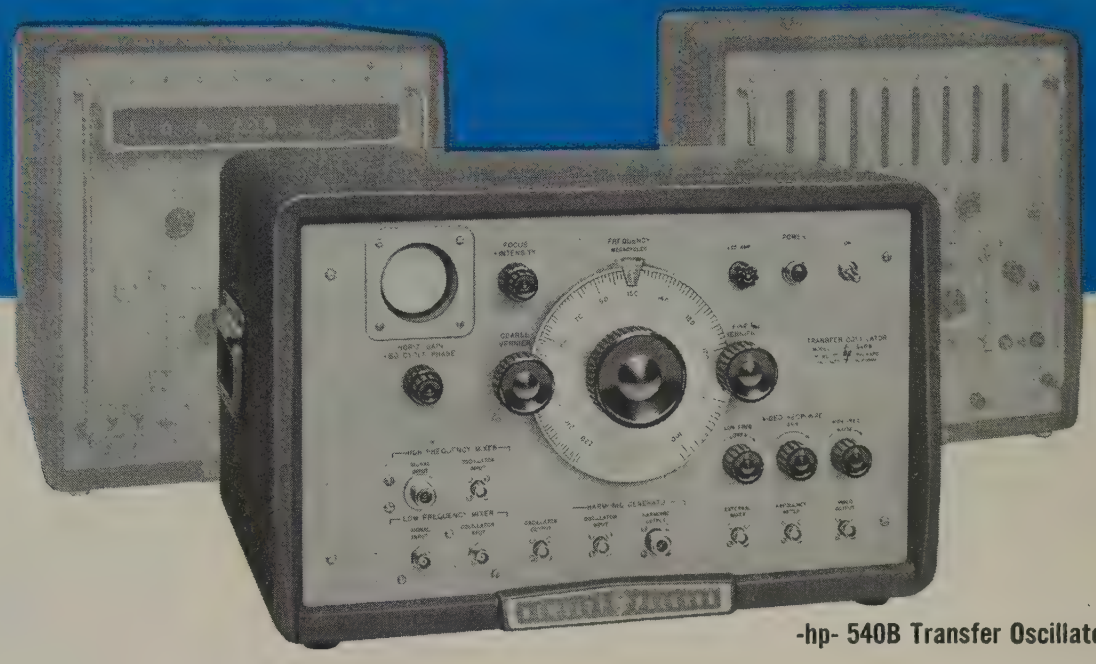
Note on Professional Group Meetings: Some of the Professional Groups conduct meetings at which there are exhibits. Working committeemen on these groups are asked to send advance data to this column for publicity information. You may address these notices to the Advertising Department and of course listings are free to IRE Professional Groups.

NEW hp TRANSFER OSCILLATOR

Permits your hp 524 series Counter to measure to 12.4 KMC with true counter accuracy, "low frequency" convenience!



-hp- 540B Transfer Oscillator

Quickly, here's what this new hp 540B Transfer Oscillator does for you:

Extends frequency counter accuracy far into the microwave region. Permits measurement of pulsed, CW, FM, AM or noisy signals. Provides multiple check for positive accuracy. Measures FM deviation. Requires no external mixer or tuning. Eliminates complex setups.

Measurements such as those listed above are made with a convenience and accuracy heretofore associated only with much lower frequencies.

Model 540B is an improved version of the popular hp 540A. It measures frequencies by comparing harmonic output with the unknown and measuring the fundamental on a counter such as hp 524 series. The instrument has a self-contained oscilloscope detector for comparison with unknown frequencies. A precision tuning control permits the oscillator harmonic to be locked with the measured frequency.

Specifications:

Frequency Range:	10 MC to 12.4 KMC
Input Signal:	CW, FM, AM or pulse
Input Signal Level:	Varies with frequency and individual crystals
Accuracy:	Depends on input signal. With stable, noise-free CW signal, accuracy approaches that of frequency counters.
Oscillator Frequency Range:	100 MC to 220 MC (fundamental) Above 12.4 KMC (harmonic)
Stability:	Less than 0.002% change per minute after warmup
Amplifier Gain:	Variable to 40 db or more
Bandwidth:	Variable. High Freq.: 3 db point adjustable 1 KC to 2 MC. Low Freq.: 3 db point switched from 100 cps to below 10 KC.
Output:	1 v rms maximum into 1,000 ohms
Oscilloscope Frequency Range:	100 cps to 200 KC
Vertical Sensitivity:	5 mv rms/inch at mixer output
Horizontal Sweep:	Internal, power supply frequency with phase control; or external, 1 v/inch, 20 cps to 5 KC.
Price:	$750.00 (cabinet) $735.00 (rack mount)

Data subject to change without notice

HEWLETT-PACKARD COMPANY

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Cable "HEWPACK" • DAvenport 5-4451

FIELD REPRESENTATIVES IN ALL PRINCIPAL AREAS

hp world leader in microwave measuring equipment

These Sylvania NPN Switching Transistors can be

on your breadboard today

You can take immediate advantage of the outstanding performance of Sylvania's most popular NPN switching transistors. They are now available, through local authorized Sylvania distributors, in a new Switching Transistor Sampler pack. It contains 3 each of the six most popular NPN types in Sylvania's extensive switching transistor line. It also contains an 8-page booklet giving complete specifications and data on each type.

Included in the pack are types 2N356, 2N357, 2N358 with 100 mw dissipation and types 2N377, 2N385 and 2N388 with 150 mw dissipation (base internally connected to case for added dissipation). Each type features the Sylvania welded hermetic seal for full protection against humidity and other environmental conditions. Each meets JEDEC TO-5 or TO-9 dimensions.

The complete 18-transistor sampler is available while this offer lasts at a suggested industrial user cost of $72.95 . . . that's $28.63 LESS than the regular small-quantity price . . . from your authorized Sylvania Distributor. He has the new package in stock now. So call, write or drop by the Sylvania Distributor near you. He'll be glad to give you full particulars on these high-stability Sylvania NPN Switching Transistors.

CHARACTERISTICS

Type	Max. Dissipation at 25° Ambient	Max. Junction Temp (°C)	Max. I_c (ma)	Current Gain h_{FE}	Max. Rise Time, t_r (Microseconds)
2N356	100 mw	85	500	30	2.0
2N357	100 mw	85	500	30	1.2
2N358	100 mw	85	500	30	0.8
2N377*	150 mw	100	200	40	2.5
2N385*	150 mw	85	200	70	—
2N388*	150 mw	100	200	110	1.0

*Base internally connected to the case

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Subsidiary of
GENERAL TELEPHONE & ELECTRONICS

Sylvania Electric Products Inc.
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100 Sylvan Rd., Woburn, Mass.

These authorized Sylvania Semiconductor Distributors can provide off-the-shelf delivery of this NPN Switching Transistor Sampler

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Mineola, L. I., N. Y.
JAmaica 6-0300
Pioneer 6-8686

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Mountainside, N. J.
ADams 2-8200

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WOrth 6-5300

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WOrth 4-3311

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BAldwin 3-9400

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South Hill Electronics
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FIeldbrook 1-6200

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SOUTH CAROLINA
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CEdar 2-6740

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HAymarket 1-6800

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TUlsa 3-1500

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FEderal 9-6346

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MOhawk 4-7700

OHIO
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CHerry 1-6530

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SUperior 1-9410

Dayton
Srepco
314 Leo Street
BAldwin 4-3871

Toledo
Warren Radio Company
Box 1004
1002 Adams Street
CHerry 8-3364

WISCONSIN
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Satterfield Electronics
1900 So. Park Street
ALpine 7-4801

Milwaukee
Radio Parts Company
940 No. 27th Street
WEst 3-5131

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TEXAS
El Paso
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KEystone 3-9555

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BRadshaw 2-0831

Radio Products Sales
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RIchmond 9-7471

Universal Radio Supply
1727 So. Los Angeles St.
RIchmond 9-5421

Oakland
Brill Electronics
610 East 10th Street
TE 2-6100

Elmar Electronics Inc.
140 11th Street
HIgate 4-7011

Pasadena
Electronic Supply Corp.
2085 E. Foothill Blvd.
RYan 1-5291

San Jose
Peninsula TV & Radio
656 South 1st Street
CYpress 4-8781

San Francisco
Zack Electronics
1426 Market Street
MArket 1-1422

WASHINGTON
Tacoma
C & G Radio Supply Co.
2502 Jefferson Avenue
BRoadway 2-3181

IRE News and Radio Notes

Calendar of Coming Events and Authors' Deadlines*

1959

Radio Frequency Interference Seminar, Park Sheraton Hotel, N. Y., N. Y., June 15–16.

Symp. on Electromagnetic Theory, Univ. of Toronto, Toronto, Can., June 15–20.

Int'l Conf. on Info. Processing, UNESCO House, Paris, France, June 15–20.

Int'l Symp. on Circuit & Information Theory, UCLA, Los Angeles, Calif., June 16–18.

6th Annual Meeting of Soc. of Nuclear Med., Palmer House, Chicago, Ill. June 18–19.

AIEE Conf. on Air Transport., Olympic Hotel, Seattle, Wash., June 24–26.

Nat'l Conv. on Mil. Elec., Sheraton Park Hotel, Washington, D. C., June 29–July 1.

Denver Res. Inst. Sixth Annual Symp. on Computers and Data Processing, Stanley Hotel, Estes Park, Colo. July 30, 31.

Natl. Ultrasonics Symp., Stanford Univ., Stanford, Calif., Aug. 17.

WESCON, San Francisco, Calif., Aug. 18–21.

Internatl. Conf. on Quantum Elec., Shawanga Lodge, Bloomingburg, N.Y., Sept. 14–16.

PGEWS Symp., Boston and Los Angeles, Sept. 17–18. (A.M. Cross, Raytheon Mfg. Co., Wayland, Mass.; J. M. Cryden, Hughes Aircraft Corp., Culver City, Calif.)

Special Tech. Conf. on Nonlinear Magnetics and Mag. Amplf., Shoreham Hotel, Washington, D.C., Sept. 23–25.

9th Annual PG on Broadcasting Symp., Willard Hotel, Washington, D.C., Sept. 25–26.

Nat'l Symp. on Telemetering, Civic Aud. & Whitcomb Hotel, San Francisco, Calif., Sept. 28–30 (DL* May 10, G. Larse, Missile Syst. Div., Lockheed Aircraft Corp., Sunnyvale, Calif.)

Symp. on Indus., Elec., Mellon Inst., Pittsburgh, Pa., Sept. 30–Oct. 1.

5th Aeronautical Comm. Symp., Hotel Utica, Utica, N.Y., Oct. 5–7.

5th Nat. Communications Symp., Hotel Utica, Utica, N.Y. Oct. 5–7. (DL*: June 30, R. L. Marks, Griffiss AFB, N.Y.)

Ann. Symp. on Interference Reduction, Museum of Sci. and Industry, Chicago, Ill., Oct. 6–8.

IRE Canadian Conv., Toronto, Can., Oct. 7–9.

1959 Internat'l. Systems Meeting of the SPA, Royal York Hotel, Toronto, Can., Oct. 12–14.

Nat'l Elec. Conf., Sherman Hotel, Chicago, Ill., Oct. 12–14.

URSI-IRE Fall Meeting, El Cortez Hotel, Balboa Park, San Diego, Calif., Oct. 19–21.

Semiconductor Sym., Fall Meeting of the Electrochemical Society, Deshler-Hilton Hotel, Columbus, O., Oct. 19–22

* DL = Deadline for submitting abstracts.

(Continued on page 15A)

RQC Calls for Papers

Abstracts of papers to be submitted for the Sixth National Symposium on Reliability and Quality Control, jointly sponsored by the IRE, the AIEE, and the ASQC, and scheduled for January 11–13, 1960, must be received by June 15, 1959.

Ten copies of the abstract of not more than 800 words are required. It should include the title of the paper (not to exceed 50 letters including spaces), the author's name, position, and affiliation—where more than one author, indicate who would present the paper. It should also indicate whether the paper concerns a new approach, success achieved, or a confirmation of theory. Ten copies of a biographical sketch of each author must accompany the abstract. Authors will be notified of acceptance by June 20, 1959. Final papers will be due October 15, 1959. Submit abstracts to M. M. Tall, 50 Flamingo St., Levittown, Pa.

WESCON New Look

The Western Electronic Show and Convention, which has already announced a "new look" for its technical sessions, will also pay formal attention to the appearances of electronic products. A joint statement was issued by WESCON's executive group and a special industrial design committee, outlining an industrial design competition open to all exhibitors at WESCON this August 18–21 at San Francisco's famed Cow Palace. O. H. Brown of Eitel-McCullough, Inc., San Carlos, Calif., show director for WESCON this year, and Harold W. Lindsay of Ampex Corp., Redwood City, Calif., chairman of the special committee, said an annual competition is being established to honor outstanding designers serving the industry and the results of their craft.

An exhibit area will be set up in the central auditorium to focus attention on the industrial design profession and to clarify the industrial designer's role as a member of the electronics product development team. Items chosen for the exhibition will receive a "WESCON Award of Merit for Industrial Design." Those judged to be particularly outstanding will receive the "WESCON Award of Excellence for Industrial Design."

To qualify for the competition entries must be a commercial system, instrument, component or other product directly related to the electronics industry. Each item must show evidence of original industrial design effort and must have been placed on the market prior to May 31, 1959. The main criteria for judging, to be done by a panel of professional industrial designers and design educators, will be visual clarity of function, ease and safety of operation, and appropriateness of appearance. The awards will be presented at the opening ceremony.

PGED Plans Fall Meeting

The Fifth Annual Electron Devices Meeting, sponsored by the IRE Professional Group on Electron Devices, will be held October 29–30 at the Shoreham Hotel, Washington, D. C., it has been announced by William J. Pietenpol, chairman of the general committee for the conference.

Abstracts of technical papers proposed for the conference should be submitted by July 31 to the technical program chairman, John A. Hornbeck, Bell Telephone Laboratories, Murray Hill, N. J. Subject matter of the proposed papers should concern developmental techniques and devices, such as electron tubes and semiconductors, rather than basic research or circuit applications.

Amendments to IRE Constitution Adopted

On March 19, 1959 the IRE Tellers committee met to count the ballots mailed to voting members on January 14, 1959 concerning amendments to the IRE Constitution.

Of the total of 40,814 ballots mailed 19,805 (48.5 per cent) were returned. Of those ballots returned 19,062 (96.2 per cent) were marked "Yes" in favor of the proposed amendments. The amended Constitution went into effect on April 20, 1959.

Some of the principal consultants to the UNESCO International Conference on Information Processing photographed at a preliminary meeting in Paris. Pictured are (*left to right*): W. L. van de Poel, Netherlands; Karl Steinbruch, a rapporteur, German Federal Republic; A. Ghizzetti, Italy; Mrs. Phillepot, Secretary to UNESCO's J. A. Mussard; A. Walther, German Federal Republic; M. V. Wilkes, United Kingdom; D. Panov, USSR; Isaac L. Auerbach, U.S.A.; and S. Comet, Sweden.

Summer Session on Industrial Dynamics

The Massachusetts Institute of Technology School of Industrial Management will offer a special two-week program on Industrial Dynamics, August 17–28, 1959. Topics to be covered include mathematical formulation of flows of information, decisions, material, money, capital equipment, and manpower; digital computer simulation studies of the causes of industrial growth and fluctuation; and discussions of future applications to production and distribution, consumer market dynamics, research and development management, and capital equipment industries.

For background information see the article "Industrial Dynamics—A Major Break-Through for Decision Makers," by Professor Jay W. Forrester of M.I.T. in the July-August issue of *Harvard Business Review*, 1958. For announcement and application form write the Summer Session Office, M.I.T., Cambridge, Mass.

NBS Publishes Radio Propagation Journal

The first issue of the *Journal of Research of the National Bureau of Standards, Section D, Radio Propagation* will be published in July, 1959, and will feature nine papers based on research carried out at the Boulder Labs. and an invited paper from J. L. Heritage, S. Weisbrod, and W. J. Fay, it was announced by James R. Wait, Editor. The journal is to be published bimonthly and subscriptions may be ordered through the Technical Information Office of the National Bureau of Standards, Washington, D. C. The subscription price is expected to be $4.00 per year.

The staff for the Radio Propagation journal includes J. R. Wait, Editor; J. W. Herbstreit, T. N. Gautier, C. G. Little, and A. G. McNish, Associate Editors; Mrs. Charlotte Landay, Secretary; and D. G. Fink and K. M. Seigel (PGAP), IRE Advisors.

ASEE Plans Electrical Division Annual Meeting

Professor A. V. Eastman of the University of Washington who is chairman of the Electrical Division of the American Society for Engineering Education has announced the details of the program for the Annual Meeting of the ASEE to be held in Pittsburgh, Pennsylvania, June 15–19.

The first formal technical session will deal with "Teaching Electrical Engineering Science Courses for Non-Electrical Students." Professor W. B. Boast will be chairman of the session which will feature papers by Professors H. A. Foecke, Notre Dame University, J. G. Truxal, Polytechnic Institute of Brooklyn, and D. W. Ver Planck, Carnegie Institute of Technology.

Professor Eastman will serve as chairman of a session entitled "Follow-Up of the Workshop on Energy Conversion Held at M.I.T. in 1957." The paper "An Integrated Lecture-Laboratory Program for Electrical Energy Conversion" will be presented by Professors D. C. White and H. H. Woodson of M.I.T. A demonstration will also be given of the "generalized machine."

Professor J. H. Mulligan of New York University will preside over a session devoted to "Part Time Graduate Study in Electrical Engineering." Scheduled for this session are four papers describing graduate programs at the New York University Graduate Center at Bell Laboratories (Prof. S. S. Shamis, N.Y.U.), in the New York Metropolitan area (Dr. A. B. Giordano, Polytechnic Inst. of Brooklyn), in the San Francisco area (Dr. J. M. Pettit, Stanford Univ.), and for the full time graduate student (Dr. T. F. Jones, Jr., Purdue Univ.).

On June 17 there will be a two-part session held at the Research Laboratories of the Westinghouse Electric Corp. The first part will be devoted to talks on "Ferrites and Ferro-Electricity," B. Davidson, Case; "Electro-Luminescence," F. E. Williams, General Electric Co.; "The Maser," I. Wieder, Westinghouse Labs.; and "Integrated Electronics—Future Electronic Building Blocks," D. Jenny, RCA Labs. The second part will be a tour of the Research Laboratories with emphasis on the work being done in the areas discussed in the first part of the session.

Air Force MARS Lists June Broadcasts

The Air Force MARS Eastern Technical Network, broadcasting on Sundays, from 2–4 P.M. (EST), on 3295, 7540, and 15,715 kc, announces the June program schedule as follows.

June 7—"Fiberglas Reinforced Plastics in Electronics," W. H. Greenberg, Research Dir., Riverside Plastics Corp.

June 14—"Air-Sea Communications Rescue Aids," T. Nehrbas, Chief Eng., Telephonics, Inc.

June 21—"Electronics in Oceanographic Surveys," G. B. Cummings and W. Lane, Telephonics, Inc.

June 28—"Project Assignments and End-of-Season Wrapup."

The Air Force MARS Eastern Technical Network will recess during the months of July and August. Weekly broadcasts will resume on September 13, 1959.

Rear Admiral Rawson Bennett II, Chief of Naval Research, was Guest Speaker at the Annual PGANE Luncheon held in New York in March. His topic was "Progress in Navy Research" and included discussion of research effort in radio astronomy, communications, and electronic components as well as of the role of basic research and the application of principles as they are discovered.

Calendar of Coming Events and Authors' Deadlines*

(Continued from page 14A)

East Coast Conf. on Aero. and Nav. Elec., Baltimore, Md., Oct. 26–28. (DL*: June 10, R. C. Spencer Martin Co., Balitmore 3, Md.)

Electron Devices Mtg., Shoreham Hotel, Washington, D. C., Oct. 29–31.

Mid. Amer. Elec. Conv., Kansas City, Mo., No. 3–4. (DL*: July 1, S. L. Levy, Midwest Res. Inst., 425 Volker Blvd., Kansas City 10, Mo., or C. A. Hatijak, Kansas State College Manhattan, Kan.)

Nat'l Conf. on Automatic Control, New Sheraton Hotel, Dallas, Tex., Nov. 4–6.

Radio Fall Mtg., Syracuse, N. Y., Nov. 9–11.

4th Conf. on Instrumentation, Atlanta, Ga., Nov. 9–11.

12th Ann. Conf. on Elec. Tech. in Med. & Bio., Sheraton Hotel, Phila., Pa, Nov. 10–12. (DL*: July 1, L. E. Flory, RCA Labs., Princeton, N.J.)

5th Internat'l. Automation Exp., N.Y., Trade Show Bldg., N.Y., N.Y., Nov. 16–20.

5th Conf. on Magnetism and Magnetic Materials Sheraton-Cadillac Hotel, Detroit Mich. Nov. 16–19. (DL*: Aug. 25, J. E. Goldman, Sci. Lab., Ford Motor Co., P.O. Box 2053, Dearborn, Mich.

1959 NEREM (Northeast Electronics Res. & Engng. Meeting), Boston Commonwealth Armory, Boston, Mass., Nov. 17–19.

Eastern Joint Comp. Conf., Hotel Statler, Boston, Mass., Dec. 1–3.

4th Midwest Symp. on Circuit Theory, Brooks Mem. Union, Marquette Univ., Milwaukee, Wisc., Dec. 1–2.

PGVC Annual Meeting, St. Petersburg, Fla., Dec. 3–4 (DL*: Jun 30, J. R. Nubauer, RCA, Camden, N.J.)

4th Midwest Symp. on Circuit Theory, Marquette Univ., Milwaukee Wisc., Dec. 1–2.

1960

IRE National Conv., N. Y. Coliseum and Waldorf-Astoria Hotel, Mar. 21–24.

SWIRECO (Southwestern Regional Conference), Houston, Texas, Apr. 20–22.

Nat'l Aeronautical Electronics Conf., Dayton, Ohio, May 2–4.

Western Joint Computer Conf., San Francisco, Calif, May 2–6.

PGMTT Natl. Symp., San Diego, Calif., May 9–11.

7th Reg. Tech. Conf. & Trade Show, Olympic Hotel, Seattle, Wash., May 16–18.

Cong. Int'l Federation of Automatic Control, Moscow, USSR, June 25–July 9.

WESCON, Los Angeles Mem. Sports Arena, Los Angeles, Calif., Aug. 23–26.

Nat'l Symp. on Telemetering, Washington, D. C., Sept.

Industrial Elec. Symp., Sept. 21–22.

Nat'l Elec. Conf., Chicago, Ill., Oct. 10–12.

East Coast Conf. on Aero & Nav. Elec., Baltimore, Md., Oct. 24–26.

Electron Devices Mtg., Hotel Shoreham, Washington, D. C., Oct. 27–29.

Radio Fall Mtg., Hotel Syracuse, Syracuse, N.Y., Oct. 31, Nov. 1–2.

* DL = Deadline for submitting abstracts.

A "Texas-Size" letter of invitation was presented to Dr. Ernst Weber (*center*), President of the IRE, at the National IRE Convention which convened in New York City on March 23–26. Making the presentation is John A. Green (*left*), of the 11th Annual Southwestern IRE Conference and Electronics Show (SWIRECO). Looking on is Dr. George Bailey, Executive Secretary of the IRE. The letter, measuring 15×20 inches, serves as an official welcome for the over 71,000 radio and electronic engineers in the United States to attend the SWIRECO Show, April 16–18, in Dallas, Texas.

Reliability Handbook Now Available from ASQC

The Electronics Division of the American Society for Quality Control has announced the publication of a reliability handbook entitled "Production and Field Reliability," edited by their Technical Publication Committee.

The book, consisting of twelve chapters, begins with basic reliability principles and theory including terms, definitions, and mathematics, and then progresses logically through the application of reliability and quality controls during the sequential steps of production and field use.

"Production and Field Reliability" is now available at $3.50 per copy from J. Bemersderfer, ASQC Electronics Division Treasurer, c/o General Electric Co., Building 500, Cincinnati 15, Ohio.

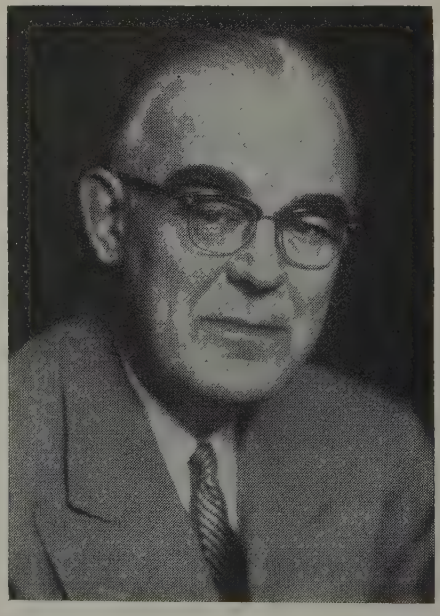
Jensen Honored by the IRE Standards Committee

Mr. Axel G. Jensen was the first guest-of-honor of the IRE Standards Committee at its Annual Luncheon held during the 1959 IRE National Convention. The Committee honored Mr. Jensen "for distinguished services to the IRE in the active encouragement of coordinated effort by committees and by other societies toward the development of uniform standards."

Dr. Ernst Weber, President of IRE, extended to Mr. Jensen the appreciation of the officers and members of the IRE for the long and energetic service which he has given to the IRE Standards activity.

Mr. Jensen has been active on various technical committees since 1938; a member of the Standards Committee since 1948, holding the offices of vice-chairman and subsequently chairman during that period. For the two years of 1955 and 1956 he was Standards Coordinator on the IRE Board of Directors. Since 1949 he has served as IRE representative on various ASA Committees, and particularly on the ASA Standards Council since 1951. He was IRE representative on several joint committees to coordinate standards activities.

He has also served as an IRE representative on the United States Delegations to international conferences, including those of the International Radio Consultative Committee and the International Electrotechnical Commission.



Axel G. Jensen, guest-of-honor of the IRE Standards Committee at its Annual Luncheon in March, was cited for his distinguished service to the Institute for the development of uniform standards.

Office of Naval Research Plans September Conference

The International Conference on Quantum Electronics—Resonance Phenomena, sponsored by the Office of Naval Research, will be held at the Shawanga Lodge, Bloomingburg, N. Y. on September 14–16, 1959. The conference will consider basic problems in physics and electronics which are important to the increasing use of molecular and atomic resonances in masers, atomic clocks, and related devices, as well as the application of "quantum electronics" to scientific problems. Among the topics to be considered are: paramagnetic resonances and relaxation; frequency and time standards based on atomic or molecular resonances; low-noise amplification by stimulated emission; optical spectroscopy of paramagnetic salts; generation of millimeter waves by maser techniques; application of cyclotron resonances in solids to electronics; generation, amplification, and detection of infrared or optical radiation by resonance techniques; and applications of "quantum electronics" to radio astronomy, high-resolution spectroscopy, and tests of relativity.

It is intended that this will be a working conference rather than a tutorial meeting. Consequently, attendance is being limited to those who are active in appropriate fields of research.

EIA Schedules Conference on Value Engineering

The EIA Engineering Department will sponsor a conference on Value Engineering, October 6–7, 1959, at the University of Pennsylvania.

The conference will be aimed at acquainting industry with the worth of the value engineering program and the proven tools of such a program which are available. Participating will be those industry members and military personnel acquainted with the successful use of value engineering tools.

R. S. Mandelkorn, of Lansdale Tube Co., will be general chairman of the symposium. He will be assisted by members of the M-5.4 Committee of Value Engineering and the EIA Engineering Department Staff.

Professional Group News

The IRE Professional Group on **Communications Systems** has elected new officers who will assume their duties on July 1, 1959. The new Chairman is J. E. Schlaikjer, ITMT Co., N. Y., N. Y. and Vice-Chairman is Capt. C. L. Engleman, Pres., Engleman and Co., Washingron, D. C. New members of the Administration Committee are A. C. Clavier, R. E. Greenquist, R. A. Kulinyi, R. L. Marks, D. C. Ports and E. Toth. R. D. Campbell, A. M. Seymour, and R. L. Vader are alternate members.

The following Chapters were approved by the IRE Executive Committee on March 30, 1959: PG on **Automatic Control**—Milwaukee Chapter; PG on **Medical Electronics**—Baltimore Chapter; PG on **Military Electronics**—Jt. Fort Huachuca, Tucson, and Phoenix Chapter; PG on **Radio Frequency Interference**—Washington, D. C. Chapter; PG on **Reliability and Quality Control**—Columbus Chapter.

Galileo Meets the Martians

One memorable day in 1633, 5 space ships suddenly materialized in the sunny Italian sky over Pisa and landed directly under the nose of Galileo's telescope. Three creatures alighted from the lead ship and made straight for Galileo.

"Good morning Signor Galilei," they chorused in unison. "We are . . ."

"Don't tell me, let me guess," interrupted the scientist. "The Mars Brothers?"

"In the flesh, more or less," leered the green one in the middle, brandishing a cigar. "I'm Sloucho. Sorry about the accident. We seem to have knocked off a Pisa the Tower."

"Good for the tourist trade," Galileo smiled.

"Now for business," went on Sloucho. "The boys upstairs are fascinated with your radar. They sent us down here to find out how you make it work without Bomac tubes."*

"I'm sorry to say it doesn't work at all," Galileo answered. "Or rather — it didn't, until the instant your ship hit the tower."

Sloucho's cigar was aquiver with excitement. "What happened then?" he asked.

"See for yourself," Galileo said, pointing a bony finger at the radar console. There, blinking crazily, like so many overstimulated lightning bugs, the tubes were actually spelling out a single, sure-enough word.

The word was "TILT."

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URSI International Symposium on Electromagnetic Theory

June 15–20, 1959, University of Toronto, Toronto, Canada

The International Symposium on Electromagnetic Theory will be held at the University of Toronto, Toronto, Ontario, Canada on June 15–20, 1959 under the sponsorship of the Union Radio Scientifique Internationale (URSI), the University of Toronto, and the IRE Professional Group on Antennas and Propagation. The Symposium will be supported by the U. S. National Science Foundation and the National Research Council of Canada. Anyone interested may register and attend the Symposium.

The registration fee is $10.00 in advance and $12.00 at the symposium. All registrants will receive the *Proceedings* of the symposium containing all the papers presented, which will be published by the PGAP in the Fall.

To register in advance, send $10.00, payable to the Symposium on Electromagnetic Theory, to Prof. V. G. Smith, Dept. of Elec. Eng., Univ. of Toronto, Toronto 5, Ontario, Canada. For other information contact Dr. George Sinclair, Symposium on Electromagnetic Theory, University of Toronto, Toronto 5, Ontario, Canada.

Monday Morning, June 15

Diffraction and Scattering Theory I

"Infinite Integral Transforms in Diffraction Theory," *P. C. Clemmow, Univ. of Michigan, Ann Arbor, Mich.*

"The Asymptotic Expansion of Electromagnetic Scattering Functions at Long Wavelengths, *K. M. Seigel and T. B. A. Senior, Univ. of Michigan, Ann Arbor, Mich.*

"Diffraction by a Circular Aperture," *J. Blazer and A. Brown, New York Univ., N. Y., N. Y.*

"Scalar Diffraction by an Elliptic Cylinder," *N. D. Kazarinoff and R. K. Ritt, Univ. of Michigan, Ann Arbor, Mich.*

"Fock Theory," *R. F. Goodrich, Univ. of Michigan, Ann Arbor, Mich.*

"High Frequency Diffraction by Strips and Discs," *B. Noble, New York Univ., N. Y., N. Y.*

Monday Afternoon

Diffraction and Scattering Theory II

"Pulse Return from a Sphere," *V. H. Weston, Univ. of Michigan, Ann Arbor, Mich.*

"Diffraction by an Inhomogeneous Sphere," *B. R. Levy and J. B. Keller, New York Univ., N. Y., N. Y.*

"New Results on Back Scattering from Cones and Spheroids," *A. Olte and S. Silver, Univ. of California, Berkeley, Calif.*

"Diffraction by Smooth Conical Obstacles," *H. E. J. Neugebauer and M. P. Bachynski, RCA Victor Res. Labs., Montreal, Canada.*

"Diffraction by Surfaces of Variable Curvature," *W. Franz and K. Klante, Münster Univ., Germany.*

"Diffraction of an Electromagnetic Plane Wave by a Funnel-Shaped Screen," *W. Braunbek, Univ. of Tübingen, Germany.*

"The Experimental Determination of the Far-Field Scattering from Simple Shapes," *J. E. Keys and R. I. Primich, Defence Res. Telecommunications Est., Ottawa, Canada.*

Tuesday Morning, June 16

Diffraction and Scattering Theory III

"Diffraction and Refraction of Plane Electromagnetic Pulses," *V. M. Papadopoulos, Brown Univ., Providence, R. I.*

"The Field of a Pulsed Dipole in an Interface," *C. S. Gardner and J. B. Keller, New York Univ., N. Y., N. Y.*

"Diffraction by Half-Plane with a Special Impedance Variation," *J. Shmoys, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.*

"On the Behaviour of Electromagnetic Waves in the Presence of Wedges with Impedance Boundary Conditions," *S. N. Karp and F. C. Karal, Jr., New York Univ., N. Y., N. Y.*

"Some New Forms of Huygens' Principle," *V. H. Rumsey, Univ. of California, Berkeley, Calif.*

"General Theorems on Radiating Waves with Applications to Surface Waves and Propagation," *J. Robieux, Compagnie Générale de télégraphie Sans Fil, Paris, France.*

"On Helmholtz's Theorem in Finite Regions," *J. Van Bladel, Univ. of Wisconsin, Madison, Wis.*

Tuesday Afternoon

Radio Telescopes

"The Synthesis of Large Radio Telescopes by the Use of Radio Interferometers," *J. R. Shakeshaft, Cavendish Lab., Univ. of Cambridge, Cambridge, England.*

"A Wide Aperture Mirror for Radio Astronomy," *G. Toraldo di Francia, Centro Microonde, Florence, Italy.*

Panel Discussion

Wednesday Morning, June 17

Surface Waves I

"Anatomy of 'Surface Waves'," *S. A. Schelkunoff, Bell Tel. Lab., Murray Hill, N. J.*

"Waves on Interfaces," *G. Goubau, USA Res. and Dev. Lab., Fort Monmouth, N. J.*

"Surface Waves Supported by Curved Surfaces," *H. M. Barlow, Univ. College London, London, England.*

"Guiding of Electromagnetic Waves by Uniformly Rough Surfaces," *J. R. Wait, Natl. Bur. of Standards, Boulder, Colo.*

"The Behaviour of Surface Waves at a Discontinuity of Surface Reactance," *J. Brown, Univ. College London, London, England.*

"On the Excitation of the Waves of Proper Solutions," *K. Furutsu, Radio Res. Labs., Kokubunji, Tokyo, Japan.*

Wednesday Afternoon

Surface Waves II

"The Surface Wave Concept in Connection with Propagation Trajectories Associated with the Sommerfeld Problem," *H. Bremmer, Res. Lab., N. V. Philips, Eindhoven, Netherlands.*

"Surface Wave Research at Sheffield," *A. L. Cullen, Univ. of Sheffield, Sheffield, England.*

"The Transmission Characteristics of a Corrugated Guide," *G. Piefke, Central Labs of the Siemens and Halske AG, München, Germany.*

"Radiation and Guided Waves," *A. E. Karbowiak, Standard Telecommunication Labs. Ltd., Enfield, Middlesex, England.*

"Guided Waves on Sinusoidally Modulated Reactance Surfaces," *A. A. Oliner and A. Hessel, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.*

"Surface Wave Antennas: Recent Accomplishments and Unsolved Problems," *F. J. Zucker, Air Force Cambridge Res. Center, Bedford, Mass.*

Thursday Morning, June 18

Surface Waves III

"On the Excitation of Surface Waves," *C. M. Angulo, Brown Univ., Princeton, R. I.*

"Surface Wave Contributions from a Lossy Conductor," *B. Friedman, Univ. of California, Berkeley, Calif.*

"Electromagnetic Properties of Wedge and Cone Surfaces with a Linearly Varying Surface Impedance," *L. B. Felsen, Polytechnic Inst. of Brooklyn, Brooklyn, N. Y.*

Panel Discussion on Surface Waves

Thursday Afternoon

Boundary Value Problems

"The Finite Range Wiener-Hopf Integral Equation and a Boundary-Value Problem in a Waveguide," *R. Mittra, Univ. of Illinois, Urbana, Ill.*

"Fields in the Neighborhood of a Caustic," *I. Kay, New York Univ., N. Y., N. Y.*

"On the Discontinuity Problem at the Input to an Anisotropic Waveguide," *A. D. Bresler, formerly Polytechnic Inst. of Brooklyn, now Jasik Labs., Westbury, N. Y.*

"A Ferrite-Filled Cylindrical Cavity," *T. S. Chu and R. G. Kouyoumjian, Ohio State Univ., Columbus, Ohio.*

"Attenuation in Wedge and Septate Waveguides," *R. M. Chisholm, Queen's Univ., Kingston, Canada.*

"Diffraction of Nearly Plane 3.2 cm Electromagnetic Waves by 45 and 90 degree Conducting Wedges," *N. E. Hedgecock and A. B. McLay, McMaster Univ., Hamilton, Canada.*

"The Matching of Parallel Dielectric Plates to Free Space," *G. C. McCormick, Natl. Res. Council, Ottawa, Canada.*

"No man can improve an original invention..."

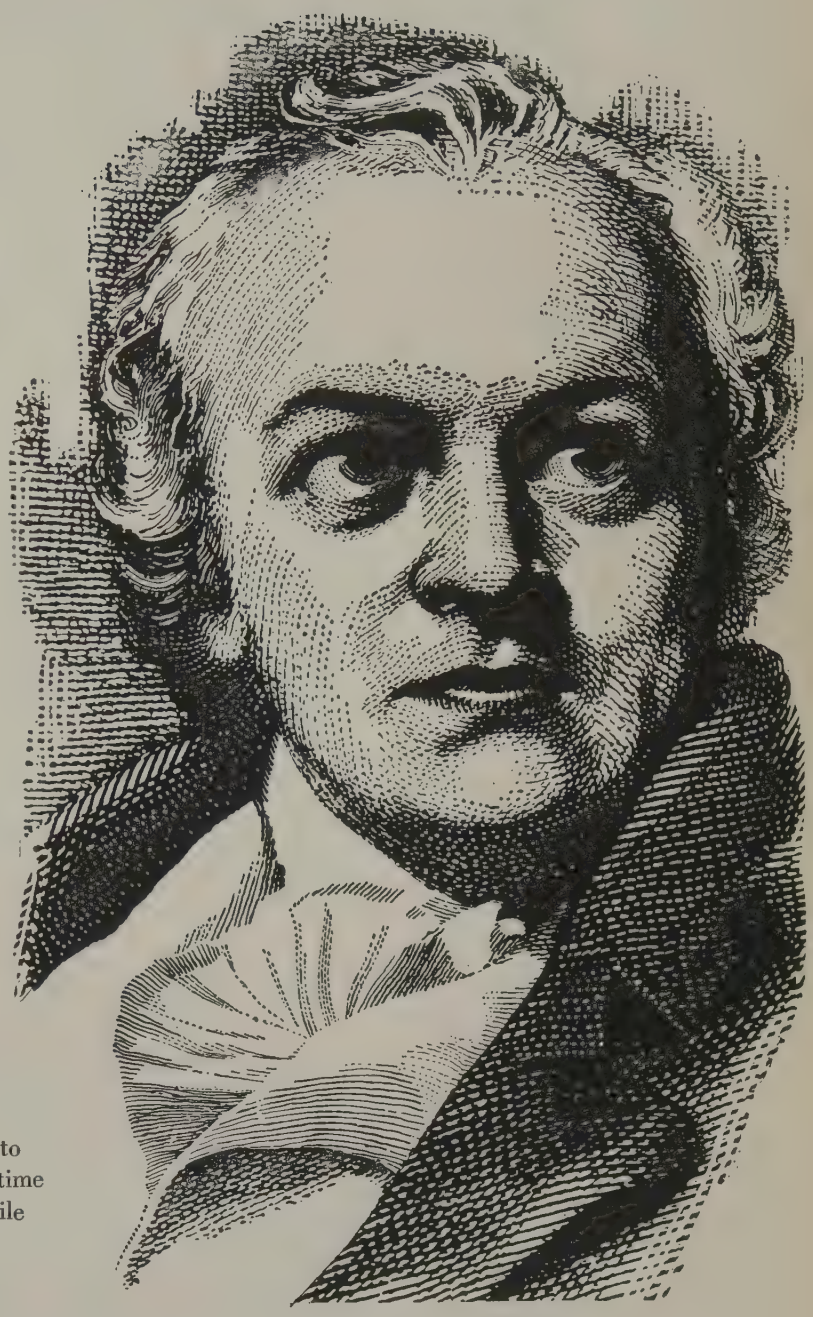
—William Blake

THERE are many scientists today who would argue this point with Blake.

At Bell Telephone Laboratories, for example, we have seen original inventions improved and re-improved countless times, the better to serve mankind.

But William Blake went on to say "... nor can an original invention exist without execution organized, delineated and articulated." Here Blake expressed ideas that apply with striking emphasis today. At Bell Laboratories organized effort is constantly aimed at fostering an environment in which inventions can exist and prosper, where they can be expressed either as ideas or in physical form, and where clear understanding of their principles can be achieved.

By helping scientists and engineers to reach for the things they seek, by organizing and coordinating their efforts, Bell Laboratories has made important contributions to the art of communications: proof of the wave nature of the electron, first research in radio astronomy, discovery of the transistor principle, invention of the feedback amplifier. Such ventures into the unknown have twice brought the Nobel Prize to Bell Laboratories scientists, and at the same time have helped create the most efficient and versatile telephone system ever known.



William Blake (1757-1827), a versatile genius, was famous for brilliant, sometimes prophetic, insights which he expressed with provocative beauty in drawing, painting, poetry and prose.

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WORLD CENTER OF COMMUNICATIONS RESEARCH AND DEVELOPMENT

Friday Morning, June 19

The Propagation of Waves through Various Media

"On the Propagation of Electromagnetic Waves through Anisotropic Layers," *G. Tyras, Boeing Airplane Co., Seattle, Wash.*

"The Electromagnetic Field in a Randomly Inhomogeneous Medium," *W. C. Hoffman, formerly Rand Corp., now at Hughes Res. Lab., Malibu, Calif.*

"Scattering by Quasi-Periodic and Quasi-Random Distributions," *V. Twersky, Sylvania Elec. Defense Labs., Mountain View, Calif.*

"Modified WKB Methods for the Propagation and Scattering of Electromagnetic Waves," *D. S. Saxon, Univ. of California, Los Angeles, Calif.*

"Interaction of Electromagnetic Waves with Some Natural Surfaces," *W. H. Peake, Ohio State Univ., Columbus, Ohio.*

"Electromagnetic Scattering by High Density Meteor Trails," *H. Brysk, Univ. of Michigan, Ann Arbor, Mich.*

"Electromagnetic Properties of High Temperature Air at Various Densities," *M. P. Bachynski, I. P. Shkarofsky, and T. W. Johnston, RCA Victor Res. Labs., Montreal, Canada.*

"The Propagation of Electromagnetic Waves in Ionised Gases," *F. H. Northover, Carleton Univ., Ottawa, Canada.*

Friday Afternoon

Antennas I

"Antennas on Circular Cylinders," *H. Lottrup Knudsen, Tech. Univ. of Denmark, Copenhagen, Denmark, and the P.E.C. Corp., Boulder, Colo.*

"Impedance Properties of Complementary Multiterminal Planar Structures," *G. A. Deschamps, Univ. of Illinois, Urbana, Ill.*

"The Bandwidth of Helical Antennas," *T. S. M. Maclean and R. G. Kouyoumjian, Ohio State Univ., Columbus, Ohio.*

"The Numerical Solution of Antenna and Scattering Problems," *G. Sinclair, Univ. of Toronto, Toronto, Canada.*

"Numerical Integration Methods for Antenna Pattern Calculations," *C. C. Allen, Gen. Elec. Co., Schenectady, N. Y.*

"The finite Conical Antenna," *S. Adachi, R. G. Kouyoumjian and R. G. Van Sickle, Ohio State Univ., Columbus, Ohio.*

Saturday Morning, June 20

Antennas II

"Resonance and Supergain Effects i Small, Dielectrically or ferromagnetically Loaded Thin, Biconical Antennas," *C. Polk RCA Labs., Princeton, N. J.*

"Calculated Phase Velocity on Long End Fire Uniform Dipole Arrays," *F. Serracchiol and C. A. Levis, Ohio State Univ., Columbus*

"Network Theory and its Relation to th Theory of Linear Systems," *J. Meixner, Insp für Theoretische Physik, Technische Hoch schule Aachen, Aachen, Germany.*

"Linear Arrays: Currents, Impedance and Fields," *R. King, Harvard Univ., Cam bridge, Mass.*

"A Critical Investigation of a Paper on the General Theory of Antennae," *S. Nyl stedt, Stockholm, Sweden.*

" New Technique for Near-Field Evalul ation," *R. C. Hansen and L. L. Bailin Hughes Aircraft Co., Culver City, Calif.*

"Back Scattering at High Frequencie from a Conducting Cylinder with Dielectri Sleeve," *R. D. Kodis, Brown Univ., Provi dence, R. I.*

Saturday Afternoon

Panel Discussion

Third National Convention on Military Electronics

JUNE 29–JULY 1, 1959, SHERATON PARK HOTEL, WASHINGTON, D. C.

The Third National Convention on Military Electronics, sponsored by the Professional Group on Military Electronics, will be held June 29–July 1, 1959, at the Sheraton-Park Hotel, Washington, D. C.

The technical program includes more than 100 papers, to be presented at 5 classified and 18 unclassified sessions. In addition, the Air Research and Development Command will present an unclassified version of its progress report. Printed copies of the 1959 *Conference Proceedings* will be distributed free to all registrants at the Convention.

On the non-technical side, there will be a Keynote Luncheon on Monday, a buffet and entertainment on Monday evening, and the Annual Banquet on the evening of June 30, featuring a prominent guest speaker. A National Committee meeting of the PGMIL will be held on the morning of June 29. No separate ladies' programs are being arranged.

Exhibits of the latest military components and equipment representing the products of more than 100 companies will fill the Sheraton-Park's air conditioned Exhibition Hall. The exhibits will run concurrently with the technical program.

Advance registration fees, which include the *Proceedings*, are $2 for IRE members; $3 for non-members; and $1 for students. At-the-door registration will be $4 for IRE members; $5 for non-members; and $1 for students. Tickets for the luncheon are $3.50; for the buffet, $5; and for the banquet, $10.

The classified sessions are sponsored by the ARDC; security clearance is required for attendance at these sessions.

Lt. Gen. William Kepner, USAF (Ret.), chairman of the board of Radiation, Inc., Orlando, Florida, is convention president. Lloyd R. Everingham, vice-president for research, Radiation, Inc., is chairman of the technical program committee.

Monday Afternoon, June 29

Missile Guidance (Confidential)

Sponsor: *Air Research and Development Command.* Moderator: (*to be announced*).

"Considerations of the Effect of Instrument Errors on the Accuracy of Inertial Guidance Systems for Ballistic Missiles," *A. H. Miller and S. L. Johnston, Army Rocket and Guided Missile Agency, (ARGMA), Redstone Arsenal, Ala.*

"Properties of Error Coefficients for Impact Accuracy Studies of Ballistic Missiles," *S. L. Johnston, ARGMA, Redstone Arsenal, Ala.*

"Airborne Digital Computer for Missiel Guidance," *N. Nesenoff, Ford Instrument Co., Long Island City, N.Y.*

"Extending our Techniques for Infrared and Optical Guidance," *W. A. Bowen, Jr., U. S. Naval Missile Center, Point Mugu, Calif.*

"Systems Organization of a Special Purpose Airborne Digital Computer," *H. H. Schiller, American Bosch Arma Corp., Garden City, N.Y.*

"A Dual-Mode Missile Homing System," *P. G. Arnold and R. G. S. Sewell, U. S. Naval Ordnance Test Station, China Lake Calif.*

Radar Techniques

Moderator: *R. S. Frazier, Cornell Aeronautical Lab., Buffalo, N. Y.*

"A Nonlinear Amplitude Tracking Technique for Filtering Pulse Signals," *W. M. Waters, Johns Hopkins Univ., Baltimore, Md.*

"Frequency Scanning Filter," *A. Applebaum, Gen. Elec., Defense Electronics Div., Syracuse, N. Y.*

"Frequency Scanning Filter Applications," *P. Howells, Gen. Elec. Co., Syracuse, N. Y.*

"PULSAR, Pulsed Light Ranging in the Visible and Near I-R Spectrum," *E. A. Kallet, Farrend Optical Co., Inc., New York, N. Y.*

"An Electronically Combined Radar Surveillance Display," *G. E. Martin, Westinghouse Elec. Corp. Baltimore, Md.*

Operations Research and Tactics

Moderator: *Dr. R. A. Weiss, Scientific Director, Army Res. Office, Washington, D. C.*

"A Simple Field Operations Research Technique for Combat Communications Systems Problems of the Long Frontier," *Lt. Col. J. R. Shirley, Booz-Allen Applied Res., Inc., Fairborn, Ohio.*

"A Digital Computer Analysis of Surface-to-Air Defenses," *A. G. Favret, System Analysis Dept., American Machine & Foundry Co., Alexandria, Va.*

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"Understanding Intercept Probability," *J. R. Wolcott, L. C. Humphrey and G. Thompson, Stromberg-Carlson Co., Rochester, N. Y.*

"Satellite Identification Problems," *R. B. Dickson, Auerbach Electronics Corp., Narberth, Pa.*

"Instrumentation and Range Safety System at Vandenberg AFB," *R. E. Hadady, Architect-Engineer Div., Aerojet-General Corp., Covina, Calif.*

Data Transmission and Processing

Moderator: *D. J. McLaughlin, U. S. Naval Res. Lab., Washington, D. C.*

"Data Processing by Optical Techniques," *L. J. Cutrona, E. N. Leith, and L. J. Porcello, Univ. of Mich., Willow Run Labs., Ann Arbor, Mich.*

"Message Composing and Entry Units," *R. F. Geiger, Data Processing Marketing, Aeronutronic Systems, Inc., Santa Ana, Calif.*

"High Speed Digital Plotter," *R. L. Sapirstein, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"An Analog Data Handling System for Aircraft Launching and Recovery Evaluation" *J. E. Frank, Reaction Motors Div., Thiokol Chemical Corp., Denville, N. J., and J. M. Noel, Tele-Dynamics, Inc., Philadelphia, Pa.*

"Digital Data Processing for Finite Memory Filters," *A. J. Monroe and R. Terzian, Res. and Analysis Dept., Litton Industries, Beverly Hills, Calif.*

Tuesday Morning, June 30

Space Electronics (Confidential)

Sponsor: *Air Research and Development Command.* Moderator: *Col. H. McD. Brown, Commander Officer, U. S. Army Signal Res. Dev. Lab., Ft. Monmouth, N. J.*

"Technological and Sociological Factors Influencing the Military Utilities of Space Vehicles," *I. Katz, Gen. Elec. Co., Ithaca, N. Y.*

"Satellite Capabilities and the Implications for Electronics," *S. Winkler, R. H. Wilcox, and F. M. Perkins, Dept. of the Navy, Office of Naval Res., Washington, D. C.*

"The Influence of Satellites on Sea Power," *Winkler, Wilcox, and Perkins.*

"Flight Control Instrumentation for Space Vehicles," *W. G. Knorr, Avionics Div., Bell Aircraft Corp., Buffalo, N. Y.*

Instrumentation I

Moderator: *M. D. McFarlane, Robertshaw-Fulton Controls Co., Anaheim, Calif.*

"An Inertial Sensing Airborne Take-Off Monitor for Jet Aircraft," *J. Kukel, I. Mayer, and W. Usry, Daystrom, Inc., Pacific Div., Los Angeles, Calif.*

"Worthwhile Approximations in Air Data Computation," *R. G. Howard and G. M. Giannini & Co., Inc., Pasadena, Calif.*

"Return Signal Build-Up in a Pulse Altimeter System," *H. J. Brudner, Emerson Radio & Phonograph Corp., Jersey City, N. J.*

"A Self Contained Flare Out System for Landing," *R. McLane, D. Markusen and R. MacGregor, Minneapolis-Honeywell Regulator Co., Aeronautical Div. Minneapolis, Minn.*

"Sonic Vibrations Analysis System," *W. E. Milberger and R. E. James, Westinghouse Elec. Corp., Kansas City, Mo.*

Navigation, Surveying and Reconnaissance

Moderator: (*to be announced*).

"An Analysis of Errors in Inertial Navigation Systems," *J. E. Anderson, Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*

"A New Aerial Surveying System," *R. S. Duggan, Lockheed Aircraft Corp., Marietta, Ga.*

"Earth Rate Inertial Navigation," *K. J. Schlager, AC Spark Plug Div., Gen. Motors Corp., Milwaukee, Wis.*

"Dead Reckoning Plotter An/APA-110," *E. G. Trunk, Servo Corp. of America, New Hyde Park, N.Y.*

"Redundant Navigation Systems," *A. Bloch, Gen. Precision Lab., Pleasantville, N. Y.*

Communications I

Moderator: *C. A. Strom, Jr., Directorate of Communications, Rome Air Dev. Center, Griffiss AFB, N. Y.*

"The Ultimate Longhaul Capability of the Tropospheric Scatter Mechanism," *C. A. Parry, Page Communications Eng., Inc., Washington, D. C.*

"A New High-Capacity Microwave Relay System," *H. R. Mathwich, R. F. Privett, and L. E. Thompson, RCA, Camden, N. J.; C. G. Arnold, RCA, New York, N. Y.; V. E. Isaac, RCA, Montreal, Canada.*

"The Demodulation of AM Signals in Noise," *J. B. Thomas, T. R. Williams, J. Wolf, and E. Wong, Princeton Univ., School of Eng., Princeton, N. J.*

"Spectrum Conservation with Phase Multilock Communication," *M. D. McFarlane and C. A. Crafts, Robertshaw-Fulton Controls Co., Anaheim, Calif.*

"Intermodulation Noise in FDM Tropospheric Scatter Communication Systems," *L. P. Yeh, Gen. Elec. Co., Philadelphia, Pa.*

"Air-to-Ground Meteoric Scatter Long Distance Communication Link (Range 500 km to 2200 km)," *K. W. Otten, J. T. Chambers, G. L. Evans, and A. J. Hannum, Wright Air Dev. Center, Wright-Patterson AFB, Ohio.*

Space Propulsion

Moderator: (*to be announced*).

"An Experimental Plasma Propulsion System," *M. J. Minneman, Republic Aviation Corp., Farmingdale, Long Island, N.Y.*

"Ionic Ram Jet Propulsion for Maintaining Satellites in Orbit Against Drag," *J. Rothstein, Edgerton, Germeshausen & Grier, Inc., Boston, Mass.*

"A Preliminary Analysis of an Ionic Thrust Device for Space Flight Applications" *R. N. Seitz and M. J. Raether, U. S. Army Ordnance Corps, Army Ballistic Missile Agency, Redstone Arsenal, Ala.*

"Some New Concepts in Missile and Space Craft Trajectory Determination," *B. E. Keiser, Missouri Res. Labs., Inc., St. Louis, Mo.*

Tuesday Afternoon, June 30

Missile Electronics (Confidential)

Sponsor: *Air Research and Development Command.* Moderator: (*to be announced*).

"The Design of a Real Time Digital Computer for a Military System," *A. Ralston, Bell Telephone Labs., Whippany Lab., Whippany, N.J.*

"Microwave Antenna Characteristics of the Ramjet Diffuser/Radiant Energy Collector," *J. K. Rozendal, U. S. Naval Missile Center, Point Mugu, Calif.*

"The Ballistic Missile Early Warning System," *R. H. Baker, RCA, Moorestown, N. J.*

"System Description of the Missile Monitor System, AN/MSG-4," *G. Cokas, Hughes Aircraft Co., Fullerton, Calif.*

"Data Processing Display Requirements of the Missile Monitor System AN/MSG-4," *A. J. Strassman, Hughes Aircraft Co., Fullerton, Calif.*

"A Description of the AN/MPS-23 Frequency Scan Radar Used in the Missile Monitor System, AN/MSG-4," *E. J. Rhoad, Hughes Aircraft Co., Fullerton, Calif.*

Radar Systems and Equipment

Moderator: (*to be announced*).

"Accuracy of a Monopulse," *D. K. Barton, RCA Defense Electronic Products, Moorestown, N.J.*

"MOPTARS—A Multi-Object Phase Tracking and Ranging System," *W. J. Zable, Cubic Corp., San Diego, Calif.*

"The Effects of Noise on a Stacked Beam Height Finding Radar," *R. A. Enstrom, Westinghouse Elec. Corp., Baltimore, Md.*

"A Radar Augmentation System Utilizing Traveling Wave Tubes," *B. Bayer and R. Dempsey, Radioplane, Van Nuys, Calif.*

"The Application of Digital Angle Encoders to Target Tracking Systems," *G. H. Wayne and Duncan G. Hunt, Wayne-George Corp., Boston, Mass.*

"A Proposed Radar Beacon for Use with Meteorological Earth Satellites," *C. P. Mook, Diamond Ordnance Fuze Lab., Washington, D. C.; D. S. Johnson, Chief Instrumentation & Observations Reduction Unit, Meteorological Satellite Section, U. S. Weather Bureau, Washington, D. C.*

Computers

Moderator: *Dr. Craig M. Crenshaw, Chief Scientist, Office of Chief Signal Officer, Washington, D. C.*)

"A Class of Supervisory Control Systems," *Dr. R. L. Cosgriff, Antenna Lab., Dep. of Elec. Eng., Ohio State Univ., Columbus, Ohio.*

"Parallel Loop Analysis of Continuous and Sampled Ballistic Missile Control Systems," *N. W. Trembath and C. M. Dickel, Space Technology Labs., Los Angeles, Calif.*

"Shrinking the Giant Brains for the Space Age," *J. J. Staller, American Bosch Arma Corp., Garden City, N. Y.*

"A New Technique for Computer Switching," *C. M. Campbell, Jr., Burroughs Res. Center, Paoli, Pa.*

"RTA Computer," *T. E. Digan, IBM, Military Products Div., Kingston, N.Y.*

Components

Moderator: (*to be announced*).

"Digital Computer Design of Electronic Type Power Transformers," *D. Wildfeuer, American Bosch Arma Corp., Garden City, N. Y.*

"The Silicon Capacitor for Military and Other High-Reliability Applications," *J. G. Hammerslag, Hughes Aircraft Co., Los Angeles, Calif.*

"Design and Application Considerations for a Low-Cross Modulation, Low-Noise,

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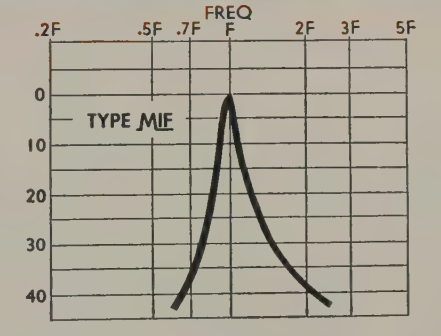

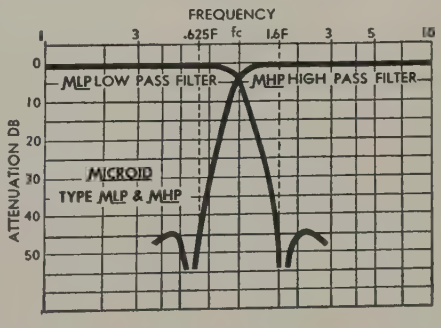

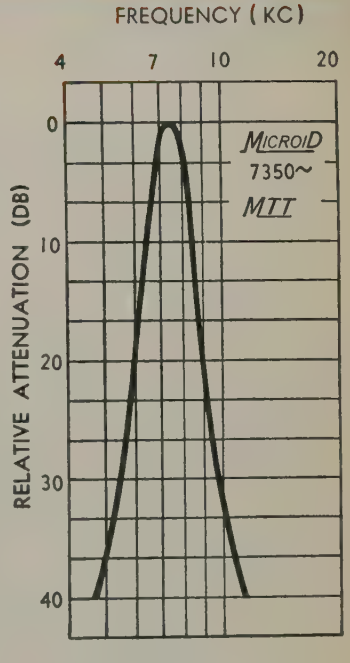

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Front-End Tube," *D. M. Burton, RCA, Harrison, N. J.*

"Development of Printed Cables and Connectors," *W. Angele, U. S. Army Ballistic Missile Group, Redstone Arsenal, Ala.*

"Microminiature 60-mc i-f Amplifier with Silicon Transistors," *C. E. Earhart and D. B. Hall, Texas Instruments, Inc., Dallas, Texas.*

Space Communications

Moderator: (*to be announced*).

"The Role of an Earth Satellite in Worldwide Military Communications," *B. R. Jacobellis, Office of the Chief Signal Officer, Washington, D. C.*

"Antenna Array for Satellite Tracking and Communication," *I. Kamen and R. Bogner, GB Electronics Corp., Valley Stream, N. Y.*

"The Atlas—SCORE Communication System," *S. P. Brown, M. Davis, H. Hawkins, and G. Senn, USASRDL, Ft. Monmouth, N. J.*

"Spin Variations of Satellite Radio Emission," *P. R. Arendt and H. P. Hutchison, Office of USASRDL, Ft. Monmouth, N. J.*

The Present Status of the Maser," *J. Weber, Univ. of Maryland, College Park, Md.*

Wednesday Morning, July 1

Detection and Tracking (Confidential)

Sponsor: *Air Research and Development Command.* Moderator: *Dr. W. J. Otting, Jr., Director of Physical Sciences, AF Office of Scientific Research, Washington, D. C.*

"Automatic-Tracking Ground Surveillance Radar," *W. C. Alexion, Bureau of Ships, Dept. of the Navy, Washington, D. C.*

"Automatic Ranging and Tracking," *A. R. Greenfield, J. W. Ryan, and J. H. Wells, Hughes Aircraft Co., Fullerton, Calif.*

"The Voltage-Tunable Magnetron—A New Tube for FM-CW Range Measuring Systems," *J. Griswold, Gen. Elec. Co., Utica, N. Y.*

"A Tactical High-Performance Three Dimensional Coverage Radar for the U. S. Marine Corps," *C. W. Gill, Bureau of Ships, Dept. of the Navy, Washington, D. C.*

"Recent Advances in Delay-Line Data Processors," *J. Wilcox and R. Thompson, Philco Corp., Philadelphia, Pa.*

Space Guidance and Tracking

Moderator: (*to be announced*).

"Miniature Control System for Space Experiments," *R. E. King and H. Low, Space Technology Labs., Inc., Los Angeles, Calif.*

"The Effect of Guidance Errors in Astroballistic Trajectories," *D. B. DeBra, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"An Inertial Guidance Technique Usable in Free Fall," *M. Streicher, R. Zehr, and R. Arthur, Bell Aircraft Corp., Buffalo, N. Y.*

"Deceleration Control of Space Vehicles," *F. H. Brady and W. G. Green, ITT Labs., Fort Wayne, Ind.*

"Satellite Tracking with Doppler," *Dr. C. S. Lorens, Jet Propulsion Lab., Calif. Inst. of Tech., Pasadena, Calif.*

"Doppler Techniques for Space Vehicle Guidance," *J. P. Campbell, Gen. Precision Lab., Pleasantville, N. Y.*

Simulation

Moderator: (*to be announced*).

"Digital Simulation of a Weapons Systems Digital Control Computer," *W. B. Fritz, J. W. Froggatt, and A. B. Kahn, AAD, Westinghouse Elec. Corp., Baltimore, Md.*

"A Signal Environment Simulator for a Passive Receiving System," *J. R. Wolcott, L. C. Humphrey and G. Thompson, Stromberg-Carlson Co., Rochester, N. Y.*

"Tactics and Diving Simulators for Training in Operation of High-Speed Submarines," *A. P. Vigliotta, U. S. Naval Training Device Center, Port Washington, N. Y.*

"Simulation for a Dynamic Analysis of an Airborne Visual Landing Aid Sight System," *R. C. McLane, Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*

"The Controllable Radar Target Simulator (CRTS)," *C. A. Hirschfield and L. Michels, System Dev. Corp., Santa Monica, Calif.*

Communications II

Moderator: *L. D. Shergalis, Electronic Design, Hayden Publishing Co., New York, N. Y.*

"Military Radio Communications Equipment Trade-Offs," *D. C. Ports, J. J. Crenca and K. Heisler, Jansky and Bailey, Inc., Washington, D. C. and E. E. Reinhart, The Rand Corp., Santa Monica, Calif.*

"The New Concept of Area Type Communications System," *J. Eggert, USASRDL, Ft. Monmouth, N.J.*

"The Simulation of Military Communication Systems," *Dr. J. Dutka, RCA Defense Electronic Products, New York, N. Y. and R. J. Meyer, RCA Defense Electronic Products, Tucson, Ariz.*

"A Compatible Synchronous Radio Teletype Systems," *G. A. Franco, Stromberg-Carlson Co., Rochester, N. Y. and B. Goldberg, USASRDL, Ft. Monmouth, N. J.*

Miscellaneous

Moderator: (*to be announced*).
Papers to be announced.

Wednesday Afternoon, July 1

Navigation and Reconnaissance (Confidential)

Sponsor: *Air Research and Development Command.* Moderator: *Dr. J. A. Boyd, Director, Willow Run Labs., Univ. of Mich., Ann Arbor, Mich.*

"A Precision Solar-Lunar Radio Sextant," *T. R. Willis and G. R. Marner, Collins Radio Co., Cedar Rapids, Iowa.*

"Application of Environment and Signal Sorting Studies to Reconnaissance Receiver Problems," *C. J. Shoens, Stanford Electronics Lab., Stanford Univ., Stanford, Calif.*

"Initial Alignment of Inertial System," *R. H. Parvin, Minneapolis-Honeywell Regulator Co., Aeronautical Div., St. Petersburg, Fla.*

"High Resolution Radar Systems," *G. O. Hall, Univ. of Mich., Willow Run Labs., Ann Arbor, Mich.*

"The Ground-to-Air Guidance Link of a Radar Drone Control System," *E. Teltscher, R. Gross, T. Oigarden and C. Valvaanis, Ford Instrument Co., Div. of Sperry Rand Corp., Long Island City, N. Y.*

"Radar Reconnaissance System AN /APS-85 Side Looking Airborne Radar," *H. N. Mottek, USASRDL, Ft. Monmouth, N. J. and G. L. Edson and D. Trego, Motorola, Inc., Phoenix, Ariz.*

Instrumentation II

Moderator: (*to be announced*).

"Holloman AFB Track Test Instrumentation Systems," *U. C. Nolte, Major, Hq. AF Missile Dev. Center, ARDC, Holloman AFB, N. M.*

"Lightweight Power Servo Transmissions for Use in Adverse Environments," *S. Sporn, American Bosch Arma Corp., Garden City, N. Y.*

"Missile A.B.U. Specifications," *A. E. Maine, The DeHavilland Aircraft of Canada, Downsview, Ontario.*

"A Nuclear Radiation Proximity Scorer," *M. J. Cohen and H. C. Gibson, Jr., Franklin Systems, Inc., West Palm Beach, Fla.*

"Vector-Miss Indicator Systems," *H. Katzman, Lockheed Aircraft Corp., Sunnyvale, Calif.*

"Military Implications of Space Age Multi-Purpose, Centralized Weapon System Test Center," *D. A. Domike, Missile Equipment Section, Packard Bell Electronics, Los Angeles, Calif.*

Guidance

Moderator: *Dr. O. Hugo Schuck, Director of Aero Research, Minneaplois-Honeywell Regulator Co., Minneapolis, Minn.*

"Generalized Inertial Guidance System Error Equations," *R. A. Moore and D. F. Meronek, Space Technology Labs., Inc., Los Angeles, Calif.*

"A Simple Two-Gyro Systems for Guidand Control," *R. A. Hoel and J. G. Nelson, Minneapolis-Honeywell Regulator Co., Minneapolis, Minn.*

"New Military Applications for Inertial and Astronertial Guidance Techniques," *T. J. Venator, Nortronics, A Division of Northrop Corp., Hawthorne, Calif.*

"Motion Coupling Effects in Missile Guidance Radiating Systems," *R. C. Smythe and J. A. Lyden, Jr., Systems, Inc., Orlando, Fla.*

"Application of a New Automatic Phase Comparator to Check Drift Rates of Inertial Reference Platforms," *H. Assmann and B. Engelhardt, Martin Co., Orlando, Fla.*

Reliability

"Moderator: *R. I. Cole, Manager, Military Projects Planning, Melpar, Inc., Falls Church, Va.*

"Diagnostic Program Techniques for SAGE Computer Maintenance," *D. F. Benkart and W. Thomson, IBM Military Products Division, Kingston, N. Y.*

"A Reliability Record," *A. P. Hendrickson, Remington-Rand Univac, St. Paul, Minn.*

"Reliable Military Electronics through Generalized Value Engineering," *D. B. Ehrenpreis, D. Ehrenpreis, N. Y., N. Y.; R. S. Cazanjian, Sperry Rand Corp., Great Neck, N.Y.*

"Reliability and Marginal Testing," *B. R. Tripp and T. K. Wright, Radiation, Inc., Orlando, Fla.*

"Communications as a Common Denominator for System Integration," *B. H. Baldridge, Gen. Elec. Co., French Road, Utica, N. Y.*

"Estimation of Duplex Computer Dependability from Simplex Data," *J. Gold, IBM Military Products Division, Kingston, N. Y.*

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1N457	60 V	20 ma @ 1.0 V	0.025 μa	5.0 μa	60 V
1N458	125 V	7 ma @ 1.0 V	0.025 μa	5.0 μa	125 V
1N459	175 V	3 ma @ 1.0 V	0.025 μa	5.0 μa	175 V
1N662	90 V	10 ma @ 1.0 V	20 μa	100 μa (@ 100° C)	50 V
1N663	90 V	100 ma @ 1.0 V	5.0 μa	50 μa (@ 100° C)	75 V
1N778	100 V	10 ma @ 1.0 V	0.5 μa	30 μa (@ 125° C)	100 V
1N779	175 V	10 ma @ 1.0 V	0.5 μa	30 μa (@ 125° C)	175 V

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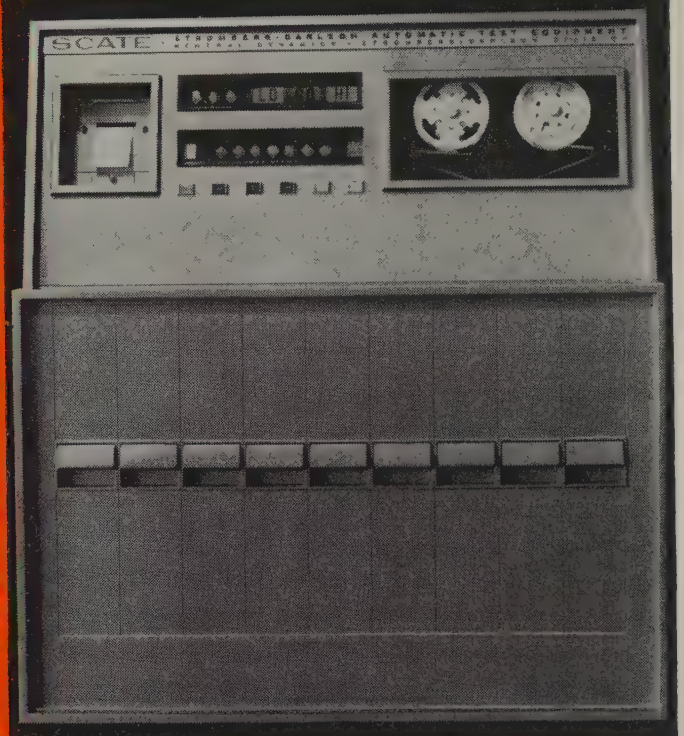

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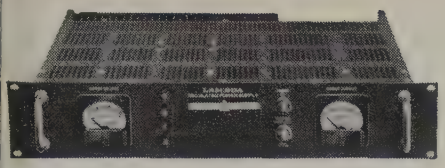

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CHECK LIST: LAMBDA REGULATED DC POWER SUPPLIES

Model	Style	Voltage Range (VDC)	Current Range (MA DC)	Regulation Impedance Ripple (Table I)	6.3 VAC Output (Amps)	Meters	Output Voltage Control	Output Terminals	Size Weight (Table II)	Price (U.S. and Canada) F.O.B. Factory College Pt., N. Y.
REGULATED POWER SUPPLIES—RACK MOUNTING										
TRANSISTORIZED										
LT-1095	Rack	0-32	0-1000	A	—	None	Rear	Rear	S-1	285.00
LT-1095M	Rack	0-32	0-1000	A	—	2½" rect	Rear	Rear	S-1	315.00
LT-2095	Rack	0-32	0-2000	B	—	None	Rear	Rear	S-1	365.00
LT-2095M	Rack	0-32	0-2000	B	—	2½" rect	Rear	Rear	S-1	395.00
TUBE REGULATED										
C-280	Rack	0-200	0-200	C	10A	None	Rear	Rear	S-2	184.50
C-280M	Rack	0-200	0-200	C	10A	3½" rect	Rear	Rear	S-2	214.50
C-281	Rack	125-325	0-200	C	10A	None	Rear	Rear	S-2	159.50
C-281M	Rack	125-325	0-200	C	10A	3½" rect	Rear	Rear	S-2	189.50
C-282	Rack	325-525	0-200	C	10A	None	Rear	Rear	S-2	169.50
C-282M	Rack	325-525	0-200	C	10A	3½" rect	Rear	Rear	S-2	199.50
C-480	Rack	0-200	0-400	D	15A	None	Rear	Rear	S-2	259.50
C-480M	Rack	0-200	0-400	D	15A	3½" rect	Rear	Rear	S-2	289.50
C-481	Rack	125-325	0-400	D	15A	None	Rear	Rear	S-2	244.50
C-481M	Rack	125-325	0-400	D	15A	3½" rect	Rear	Rear	S-2	274.50
C-482	Rack	325-525	0-400	D	15A	None	Rear	Rear	S-2	259.50
C-482M	Rack	325-525	0-400	D	15A	3½" rect	Rear	Rear	S-2	289.50
C-880	Rack	0-200	0-800	E	20A	None	Rear	Rear	S-3	340.00
C-880M	Rack	0-200	0-800	E	20A	3½" rect	Rear	Rear	S-3	370.00
C-881	Rack	125-325	0-800	E	20A	None	Rear	Rear	S-3	315.00
C-881M	Rack	125-325	0-800	E	20A	3½" rect	Rear	Rear	S-3	345.00
C-882	Rack	325 525	0-800	E	20A	None	Rear	Rear	S-3	360.00
C-882M	Rack	325-525	0-800	E	20A	3½" rect	Rear	Rear	S-3	390.00
C-1580	Rack	0-200	0-1500	F	30A	None	Rear	Rear	S-4	550.00
C-1580M	Rack	0-200	0-1500	F	30A	3½" rect	Rear	Rear	S-4	580.00
C-1581	Rack	125-325	0-1500	F	30A	None	Rear	Rear	S-4	575.00
C-1581M	Rack	125-325	0-1500	F	30A	3½" rect	Rear	Rear	S-4	605.00
C-1582	Rack	325-525	0-1500	F	30A	None	Rear	Rear	S-4	650.00
C-1582M	Rack	325-525	0-1500	F	30A	3½" rect	Rear	Rear	S-4	680.00
28	Rack	200-325	0-100	G	3A	None	Rear	Rear	S-5	59.50
28M	Rack	200-325	0-100	G	3A	3½" rect	Rear	Rear	S-5	89.50
29	Rack	100-200	0-100	H	3A	None	Rear	Rear	S-5	69.50
29M	Rack	100-200	0-100	H	3A	3½" rect	Rear	Rear	S-5	99.50
32	Rack	200-325	0-300	J	2 @ 5A	None	Rear	Rear	S-6	139.50
32M	Rack	200-325	0-300	J	2 @ 5A	3½" rect	Rear	Rear	S-6	169.50
33	Rack	100-200	0-300	J	2 @ 5A	None	Rear	Rear	S-6	154.50
33M	Rack	100-200	0-300	J	2 @ 5A	3½" rect	Rear	Rear	S-6	184.50
50R	Rack	0-500	0-500	K	2 @ 5A	4½" rect	Front	Fr & rear	S-7	420.00
		0-50	Bias	L						
		0-200	High Imped.	M						
REGULATED POWER SUPPLIES—PORTABLE AND BENCH										
25	Bench	200-325	0-100	G	3A	None	Front	Front	S-8	69.50
26	Bench	100-200	0-100	H	3A	None	Front	Front	S-8	79.50
50	Bench					See Model 50R above			S-9	440.00
71	Portable	0-500	0-200	N	2 @ 5A	3½" rect	Front	Front	S-10	310.00
		0-50	Bias	P						
		0-200	High Imped.	Q						

TABLE I

DC OUTPUT VOLTAGE REGULATION, IMPEDANCE, RIPPLE

	REGULATION Line (105-125 VAC)	REGULATION Load (min to max)	Internal Impedance (ohms)	Ripple, rms (millivolts or %)
	Less than	Less than	Less than	Less than
A	0.15% or 20MV	0.15% or 20MV	0.50	1 mv
B	0.15% or 20MV	0.15% or 20MV	0.025	1 mv
C	0.15% or 0.3V	0.25% or 0.5V	6	3 mv
D	0.15% or 0.3V	0.25% or 0.5V	3	3 mv
E	0.15% or 0.3V	0.25% or 0.5V	1.5	3 mv
F	0.15% or 0.3V	0.25% or 0.5V	0.75	3 mv
G	1%	1%	10	10 mv
H	1%	1%	10	5 mv
J	1%	1%	4	10 mv
K	0.15% or 0.1V	0.5% or 0.3V	2	8 mv
L	0.1%	unregulated	3,300	2 mv
M	0.1%	unregulated	17,500	5 mv
N	0.15% or 0.3V	0.15% or 0.3V	4	5 mv
P	0.1%	unregulated	5,500	2 mv
Q	0.1%	unregulated	25,000	5 mv

TABLE II

SIZES AND WEIGHTS

	Size H x W x D (Inches)	WEIGHT Net (lbs)	WEIGHT Shipping (lbs)
S-1	3½ x 19 x 14⅜	35	65
S-2	5¼ x 19 x 14⅜	53	80
S-3	7 x 19 x 14⅜	84	100
S-4	8¾ x 19 x 14⅜	120	140
S-5	5¼ x 19 x 8	19	23
S-6	10½ x 19 x 9¼	42	52
S-7	10½ x 19 x 14¼	89	140
S-8	8 x 14 x 6	19	23
S-9	12½ x 22 x 15	110	158
S-10	13 x 8¾ x 14½	49	85

GENERAL SPECIFICATIONS

Sufficient tolerance is incorporated in the specifications to allow for normal commercial component and tube deviations. Tube replacements may be made with any equivalent tubes meeting E.I.A. specifications.

INPUT 105-125 VAC, 50-400 CPS, single phase. Exceptions: Models 50, 50R and 71 — 105-125 VAC, 50-60 CPS.

DC OUTPUT *Voltage Range:* Continuously variable over ranges specified, except where otherwise noted.
Current Range: The current ranges given apply to the entire DC output voltage range, and for input voltages from 105 to 125 VAC. No "de-rating" is necessary.
Polarity: Either positive or negative terminal may be grounded.

AC OUTPUT The AC output is unregulated, isolated and ungrounded. It has a value of slightly higher than 6.3 V (when fully loaded) at an input of 115 VAC. This value allows for voltage drop in connecting leads. Dual outputs may be connected in series or parallel.

DUTY CYCLE Continuous duty at full load.

METERS Where meters are indicated, a separate voltmeter and milliammeter are provided.

OVERLOAD PROTECTION Ample protection is provided against external overload and internal failure conditions by means of fuses.
Circuit breakers of the magnetic, "trip-free" type are employed in Models 50, 50R, 71 and LT series as protection against external overloads. And in the LT series, the transistor complement is independently protected by special transistor circuitry.

STYLE Rack Models are designed for mounting on standard 19" relay racks.

Bench Models are provided with compact, specially-designed, ventilated cabinets equipped with carrying handles. The power supply units may be removed from their cabinets for mounting in standard relay racks (except Models 25, 26 and 71).

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28.0.1 General Definitions

E. E. Loebner, *Chairman*

S. J. Angello
R. L. Pritchard
R. M. Ryder

28.0.2 Cryogenic Devices

A. E. Slade, *Chairman*

D. A. Buck
J. W. Bremer
R. de Lano
H. T. Mann
V. L. Newhouse
F. W. Schmidlin
M. C. Steele

28.4 Semi-Conductor Devices

J. M. Early, *Chairman (IRE)*
A. C. Sheckler, *Chairman (AIEE)*

George Abraham
J. B. Angell
E. N. Clarke
A. Coblenz
S. K. Ghandhi
J. M. Goldey
B. Jacobs
J. D. Johnson
C. H. Knowles
R. P. Lyon
Roy Morrison
C. W. Mueller
M. B. Prince
R. L. Pritchard
B. J. Rothlein
H. N. Sachar
A. P. Stern
R. L. Trent
R. Ure

28.4.2 Methods of Test for Transistors for Linear CW Transmission Service

A. Coblenz, *Chairman*

28.4.3 Definitions and Letter Symbols of Semiconductors

B. J. Rothlein, *Chairman*

28.4.4 Methods of Test for Semiconductor Devices for Large-Signal Applications

R. L. Trent, *Chairman*

A. W. Berger
F. H. Blecher
R. S. Hill
C. Huang
R. M. LeLacheur

28.4.5 Methods of Test for Bulk Semiconductors

E. N. Clarke, *Chairman*

G. Bemski
D. C. Cronemeyer
I. Drukaroff
A. Kestenbaum
M. F. Lamorte
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D. T. Stevenson

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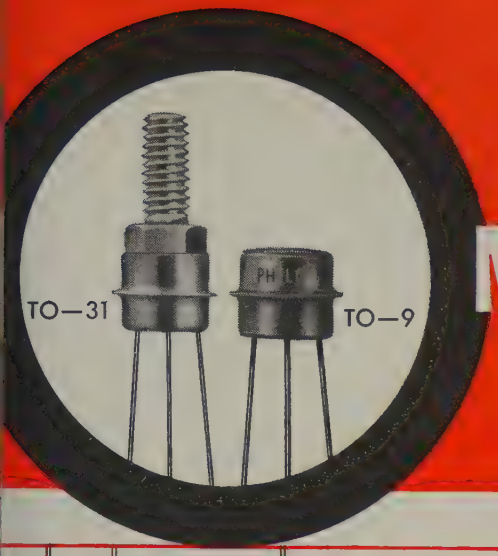
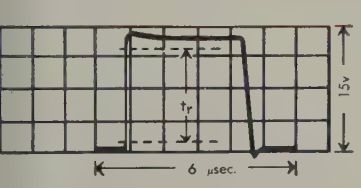


Type	Outline	Max. Readings			General Performance		"ON" Switch Performance	
		P_T mw	V_{CB} volts	I_C ma	Min. $f_{\alpha b}$ mc	Typical h_{FE} $V_{CE} = -1v, I_C = -100$ ma	Max. V_{CE}	Max. V_{BE}
N597	TO-9	250	45	400	3	70	0.2	0.34
N1123	TO-31	750*	45	400	3	70	0.2	0.34
N598	TO-9	250	30	400	5	85	0.2	0.34
N600	TO-31	750*	30	400	5	85	0.2	0.34
N599	TO-9	250	30	400	12	105	0.2	0.34
N601	TO-31	750*	30	400	12	105	0.2	0.34

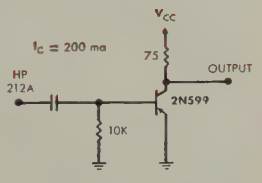
*Peak Dissipation at 25°C=1 Watt

TYPICAL RISE TIME CIRCUIT

2N599

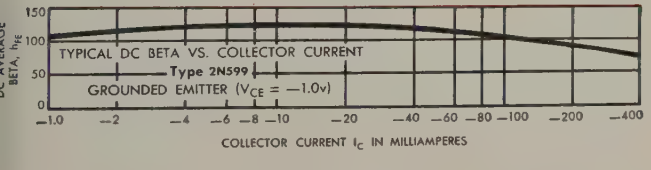


SWITCHING TIMES



TEST CIRCUIT

TYPICAL DC BETA VS. COLLECTOR CURRENT



Make Philco your prime source for all transistor information and prices. Write Dept. IR-659

- **High Dissipation: to 1 watt peak at 25°C**
- **High Current: Max. I_C = —400 ma**
- **High Temperature: 100° C Max.**
- **High Voltage: Max. V_{CB} to —45v**
- **High Frequencies: Min. $f_{\alpha b}$ to 12 mc**

Philco's complete family of PNP germanium alloy junction transistors is available in both studded and unstudded cases (TO-31 and TO-9), permitting operation at power levels as high as 1 watt peak. They offer the designer complete flexibility, providing a choice within each form factor to meet circuit requirements for voltage, gain and frequency. These transistors feature a unique, patented, cold-welded *copper* housing and internal construction that result in lower junction temperatures at normal operating power levels. (K factor as low as 0.1° C/mw.) Their design insures improved life and reliability at temperatures as high as 100° C.

The high beta of these transistors at high current makes them particularly applicable to medium speed flip-flops, logic gates, drum writers and core-driver circuits. The 30v to 45v collector rating provides the high level logic swings required in many data processing equipments. The entire family is available in production quantities . . . and in quantities 1-99 from your local Philco Industrial Semiconductor Distributor.

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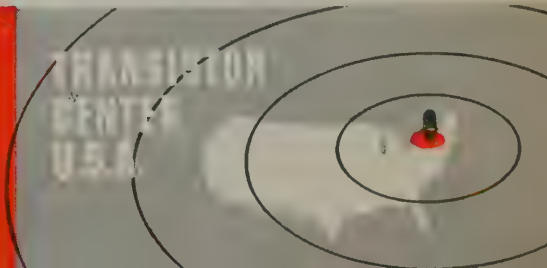

28.4.6 PHOTO DEVICES

M. B. Prince, *Chairman*

M. Adelman
J. T. Cataldo
R. Christensen
J. Defandorf
G. Dermit
A. J. Hodges
I. A. Lesk
D. E. Sawyer

28.4.7 TRANSISTOR INTERNAL PARAMETERS

R. L. Pritchard, *Chairman*

R. B. Adler
J. B. Angell
J. M. Early
W. M. Webster

28.4.8 SEMICONDUCTOR DEVICES SYMBOLS

S. K. Ghandhi, *Chairman*

B. J. Rothlein

28.4.9 SEMICONDUCTOR DIODE DEFINITIONS

C. H. Knowles, *Chairman*

L. D. Armstrong
D. C. Dickson
B. Jacobs
J. D. Johnson
R. P. Lyon
R. H. Rediker
A. C. Sheckler
J. R. Thurrell

28.4.10 SEMICONDUCTOR DIODE MEASUREMENTS

B. Jacobs, *Chairman*

A. Bakanowski
R. Doyle
D. R. Fewer
J. Fishel
J. H. Forster (alternate)
J. Gillette
C. Irwin (alternate)
E. F. Platz

A. C. Sheckler

28.4.11 THERMOELECTRIC DEVICES

Roland Ure, *Chairman*

F. Anders
I. Cadoff
F. Donahoe
R. W. Fritts
N. Fuschillo
M. A. Gross
T. Harman
P. Klein
E. H. Lougher
R. G. Sickert
M. E. Talaat
R. H. Vought

28.4.12 DEFINITIONS AND METHODS OF TEST FOR P-N-P-N DEVICES

J. M. Goldey, *Chairman*

F. Burns
R. Biesele
N. Holonyak, Jr.
F. S. Stein

28.4.13 HIGH FREQUENCY DIODES

E. N. Clarke, *Chairman*

A. Bakanowski
R. A. Campbell
E. Feldman
N. Houlding
W. G. Matthei
S. Mayburg
C. Messenger
E. L. Steele

A. Uhlir, Jr.

28.5 DIELECTRIC DEVICES

E. E. Loebner, *Co-Chairman (IRE)*
F. A. Schwertz, *Co-Chairman (AIEE)*

J. H. Armstrong
R. E. Benn
W. Bixby
J. Bramley
H. Diamond
H. Epstein
R. B. Gray
N. R. Kornfield
E. F. Mayer
C. F. Pulvari
J. R. Roeder
C. A. Rosen
E. A. Sack
R. M. Schaffert
C. F. Spitzer
P. N. Wolfe

28.5.1 NON-LINEAR DIELECTRIC DEFINITIONS

P. N. Wolfe, *Chairman*

T. W. Butler
H. Diamond
R. A. Fotland
N. R. Kornfield
E. E. Loebner
H. I. Oshry
C. F. Pulvari
N. Rudnick
E. A. Sack
C. F. Spitzer

28.5.2 DIELECTRIC ELECTRO-OPTIC DEFINITIONS

J. Bramley, *Chairman*

F. Darne
W. Gardner
F. Gordon
M. S. Hall
R. E. Halsted
H. L. Ivey
E. E. Loebner
R. Rulon
E. A. Sack
F. A. Schwertz

C. F. Spitzer

28.5.3 DEFINITIONS, FORMATION AND UTILIZATION OF ELECTROSTATIC IMAGES

R. M. Schaffert, *Chairman*

R. E. Benn
W. Bixby
H. Epstein
E. F. Mayer
J. S. Rydz
F. A. Schwertz

L. E. Walkup

28.7 MASERS AND VARIABLE REACTANCE TRANSDUCERS

J. B. Angell, *Chairman*

R. Adler
A. D. Berk
E. N. Clarke
R. S. Engelbrecht
H. J. Evans
W. H. From
V. R. Learned
W. G. Matthei
J. W. Meyer
B. Salzberg
H. Seidel
A. Uhlir, Jr.
P. H. Vartanian, Jr.
G. Wade

J. P. Wittke

21. SYMBOLS

R. T. Haviland, *Chairman*
H. P. Westman, *Vice-Chairman*

E. W. Borden
J. M. Carroll
M. C. Cisler
D. Drusdow
W. A. Ford
M. M. London
I. L. Marin
C. D. Mitchell
E. W. Olcott
R. V. Rice
M. P. Robinson
R. M. Stern
R. G. Stranix
H. R. Terhune

21.3 FUNCTIONAL SYMBOLS FOR SWITCHING AND CONTROL EQUIPMENT

E. W. Olcott, *Chairman*

R. G. Buscher
V. C. Christensen
F. Daly
H. J. Elschner
H. F. Herbig
T. H. Jeffery
E. W. Jervis, Jr.
J. J. Lamb
W. G. McClintock
F. T. Meyer
J. S. Osborne
T. J. Reilly

W. J. Wichtendahl

21.5 NEW PROPOSALS AND SPECIAL ASSIGNMENTS

M. P. Robinson, *Chairman*

21.7 LETTER SYMBOLS

R. G. Stranix, *Chairman*

J. M. Carroll
P. R. Clement
R. M. Enslow
C. C. Foster
R. M. Foster, Jr.
D. M. Howell
J. A. Raper
H. P. Westman

22. TELEVISION SYSTEMS

W. F. Bailey, *Chairman*
R. N. Harmon, *Vice-Chairman*

M. W. Baldwin, Jr.
J. E. Brown
K. A. Chittick
C. G. Fick
D. G. Fink
P. C. Goldmark
J. E. Hayes
A. G. Jensen
R. D. Kell
D. C. Livingston
H. T. Lyman
J. B. Minter
A. F. Murray
D. W. Pugsley
D. B. Smith
W. T. Wintringham

22.2 TELEVISION PICTURE ELEMENT

D. C. Livingston, *Chairman*

A. V. Bedford
J. B. Chatten
P. Mertz
T. V. Zaloudek

23. VIDEO TECHNIQUES

G. L. Fredendall, *Chairman*
J. M. Barstow, *Vice-Chairman*

I. C. Abrahams
S. W. Athey
K. B. Benson
S. Deutsch
V. J. Duke
J. R. Hefele
J. L. Jones
W. J. Poch

23.1 DEFINITIONS

S. Deutsch, *Chairman*

R. F. Cotellessa
V. J. Duke
R. M. Fraser
F. Herr
R. N. Hurst
A. Macovski

J. H. Roe

23.3 VIDEO SYSTEMS AND COMPONENTS METHODS OF MEASUREMENT

I. C. Abrahams, *Chairman*

G. M. Glassford
J. R. Hefele
A. Lind
N. E. Sprecher
E. Stein
W. B. Whalley

23.4 VIDEO SIGNAL TRANSMISSION METHODS OF MEASUREMENT

J. M. Barstow, *Chairman*

A. B. Ettlinger (alternate)
F. J. Herr
R. M. Morris
J. R. Popkin-Clurman
E. B. Pores
E. H. Schreiber
L. Staschover
D. Taylor (alternate)
J. W. Wentworth
W. B. Whalley

J. F. Wiggins

24. WAVE PROPAGATION

M. Lindeman Phillips, *Chairman*
A. B. Crawford, *Vice-Chairman*

H. H. Beverage
H. G. Booker
K. Bullington
C. R. Burrows
T. J. Carroll
A. G. Clavier
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J. H. Dellinger
F. H. Dickson
H. Fine
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M. Katzin
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J. C. Simon
R. J. Slutz
R. L. Smith-Rose
J. B. Smyth
A. W. Straiton
O. G. Villard, Jr.
J. P. Voge
J. R. Wait
A. T. Waterman

A. H. Waynick

24.1 STANDARDS AND PRACTICES

H. O. Peterson, *Chairman*

24.2 TROPOSPHERIC PROPAGATION

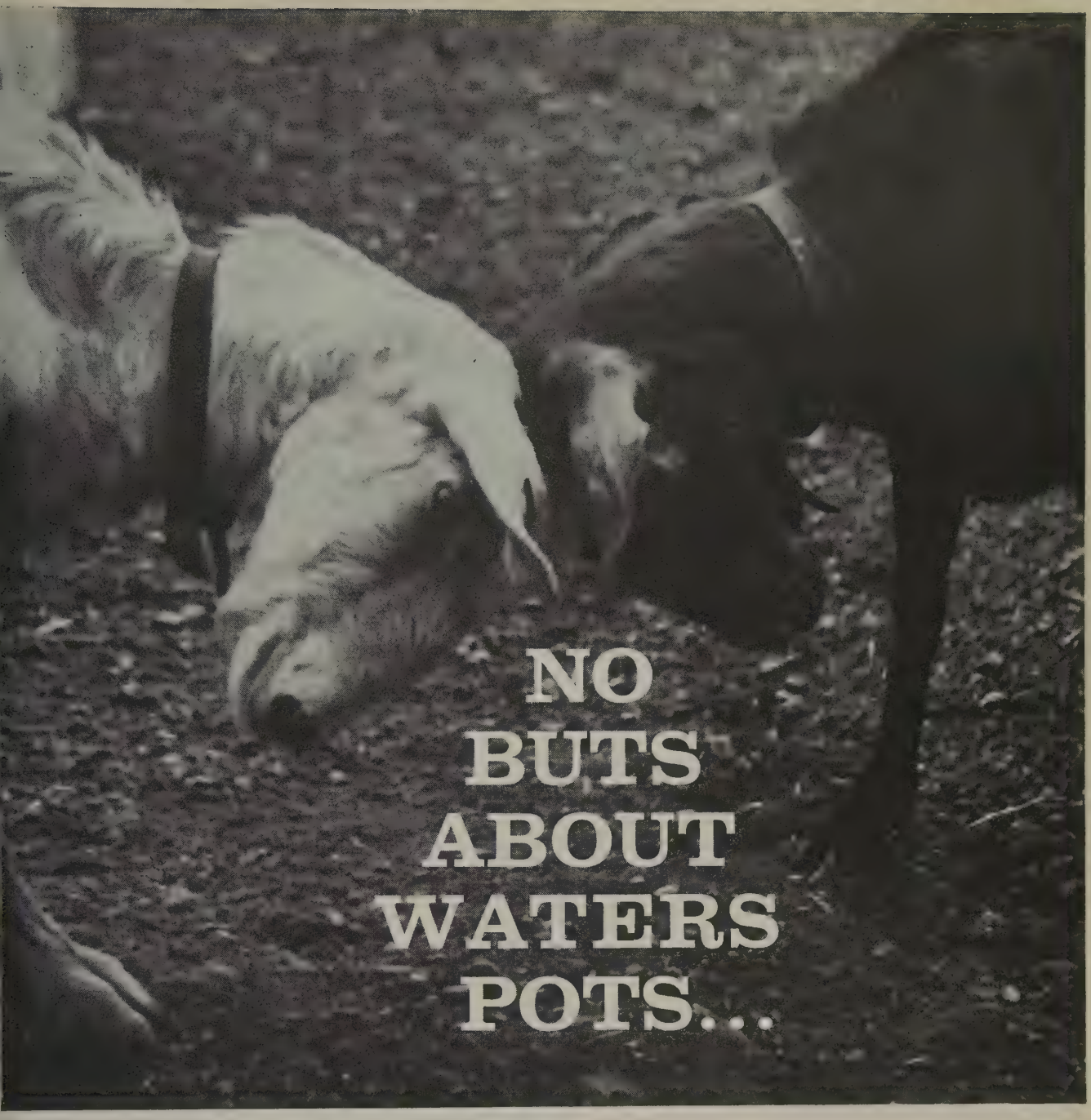
T. J. Carroll, *Chairman*

24.3 IONOSPHERIC PROPAGATION

O. G. Villard, Jr., *Chairman*

24.4 RADIO PROPAGATION HISTORY

H. H. Beverage, *Chairman*



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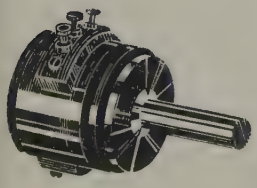

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*Oklahoma, Univ. of: C. E. Harp
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*Pennsylvania State Univ.: W. J. Ross
*Pittsburgh, Univ. of: J. Brinda, Jr.
Portland, Univ. of: W. Vassallo
*Pratt Institute: D. Vitrogan
*Provincial Inst. of Tech. & Art.: W. Partin
*Princeton Univ.: J. B. Thomas
Providence College: E. B. Halton
Puerto Rico, Universidad de: B. Dueno
*Purdue Univ.: W. H. Hayt, Jr.
Queens Univ.: H. H. Stewart
RCA Institutes, Inc.: B. S. Anolik
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*Rensselaer Poly. Inst.: H. D. Harris
*Rhode Island, Univ. of: M. J. Prince
*Rice Institute: C. R. Wischmeyer
Rochester Inst. of Tech.: C. F. Piotraschke
*Rose Polytechnic Inst.: P. D. Smith
Royal Military College of Canada: W. D. Ryan
Royal Tech. Univ. of Denmark: G. Bruun
*Rutgers Univ.: C. V. Longo
*Ryerson Inst. of Tech.: E. L. Palin
Sacramento State College: E. Ackerlind
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*San Diego State College: C. R. Moe
*San Jose State College: H. Engwicht
*Santa Clara, Univ. of: H. P. Nettesheim
*Saskatchewan, Univ. of: A. M. Michalenko
*Seattle Univ.: D. K. Reynolds
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*South Dakota State College of Agric. & Mechanic Arts: J. N. Cheadle
*South Dakota School of Mines & Tech.: D. R. Macken
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POLYCRYSTALLINE SILICON SPECIFICATIONS				
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IA	500	250	3:1	0.5
I	100	50	3:1	0.5
II	50	20	3:1	1.0
III	25	10	3:1	2.0
IV	2.5	1.0	3:1	4.0

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Reliability, weight, and size are critical in every aircraft and missile component. Hydro-Aire's new dc-to-dc power supply, being completely transistorized, is smaller and lighter than conventional dynamotors, offers many other advantages: No moving parts, no brush wear or replacement, no brush dust, no arcing. Increased efficiency (up to 90%) means further weight savings since smaller 28-volt batteries can be used.

Model 50-021, shown above contrasted with conventional dynamotor it replaces, has these characteristics:

Output voltage: 150vdc ±1%
Output current: 100ma to 200 ma
Input voltage: 28vdc ±10%
Life: 1000 hours plus
Overload characteristics: short-circuit-proof
Temperature range: —55°C to +71°C
Size: 2 x 3⅝ x 4⅜ inches
Weight: 27 oz.
Applicable specifications: MIL-E-5272, MIL-I-6181, MIL-E-7894, MIL-E-8189

Hydro-Aire solid-state power supplies are available built to any special requirements up to 10kv and 3kw, with regulation down to ±0.1%. Write today for details on Hydro-Aire's extensive line of solid-state devices.

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RAYTHEON "FIRSTS" IN THE FIELD include:

First to produce Junction Transistors in commercial quantities 16

First to insure reliable Transistor performance by developing the Raytheon Fusion-Alloy process 15

First to make low-noise Junction Transistors commercially available 14

First to develop and introduce High Frequency Fusion-Alloy Transistors 13

First to offer Fusion-Alloy Transistors specially designed, manufactured and tested for computer (switching) applications 12

First to manufacture Computer Transistors meeting military specifications 11

First to design and produce "Submin" Transistors 10

First to produce PNP Silicon Transistors for standard industrial applications 9

First to make available both PNP and NPN Silicon Transistors 8

First to mass produce diffused junction Silicon Rectifiers 7

First to introduce Ultra-High Frequency Germanium Mixer Diodes 6

First to engineer and build automatic test equipments for quality control of Transistors and to use them on a full production scale. 5

RAYTHEON qualifies as your No. 1 source of Transistors and Rectifiers that meet MILITARY requirements as specified by MIL-T-19500A and MIL-E-1D. 4

RAYTHEON keeps pace with fast-changing, fast growing demands. Raytheon's production facilities are steadily expanding in order to back up and still further enhance the Raytheon reputation as the most reliable source of reliable Semiconductors. 3

RAYTHEON is right at your elbow with sales engineers strategically located for prompt service, and backed by a fully experienced Application Engineering Department to provide genuine technical assistance. 2

RAYTHEON enjoys a world-wide reputation for product quality and reliability. 1

COUNT ON:

Raytheon PNP and NPN Fusion-Alloy Silicon Transistors for large signal, small signal, and low-noise applications. Advantages include low saturation voltage; 20 volt BVEBO; minimum change in characteristics with temperature, current and voltage; welded, hermetically sealed TO-5 package.

Raytheon Germanium Computer Transistors meet the stringent requirements of Military specifications including electrical, mechanical, and environmental tests. Switching currents to 1 ampere; high frequency, high gain; low saturation resistance; H_{FE} control at high current. Available in both TO-5 and SUBMIN packages.

Raytheon General Purpose Germanium Transistors including high frequency, audio frequency, low noise and radio receiver types. Available in TO-5 and SUBMIN packages.

Raytheon Diffused Junction Silicon Rectifiers in both wire-in and stud types, welded, hermetically sealed. Noted for their high forward conductance, exceptional reverse recovery.

Raytheon Silicon Diodes, featuring low reverse current, high forward conductance and excellent stability in high temperature applications. All subject to environmental quality control. Available in a wide range of characteristics.

Raytheon Germanium Diodes in a wide variety of both popular and special types — point contact and gold bonded. Available in standard and small glass packages.

Raytheon Circuit-Paks of Transistors, Diodes, Rectifiers and other components offer better utilization of space, ease of assembly and extreme reliability. These compact, encapsulated, complete, subassemblies, such as Phase Comparators, Bridges, Choppers, and Flip-Flops are available from stock or to your specifications.

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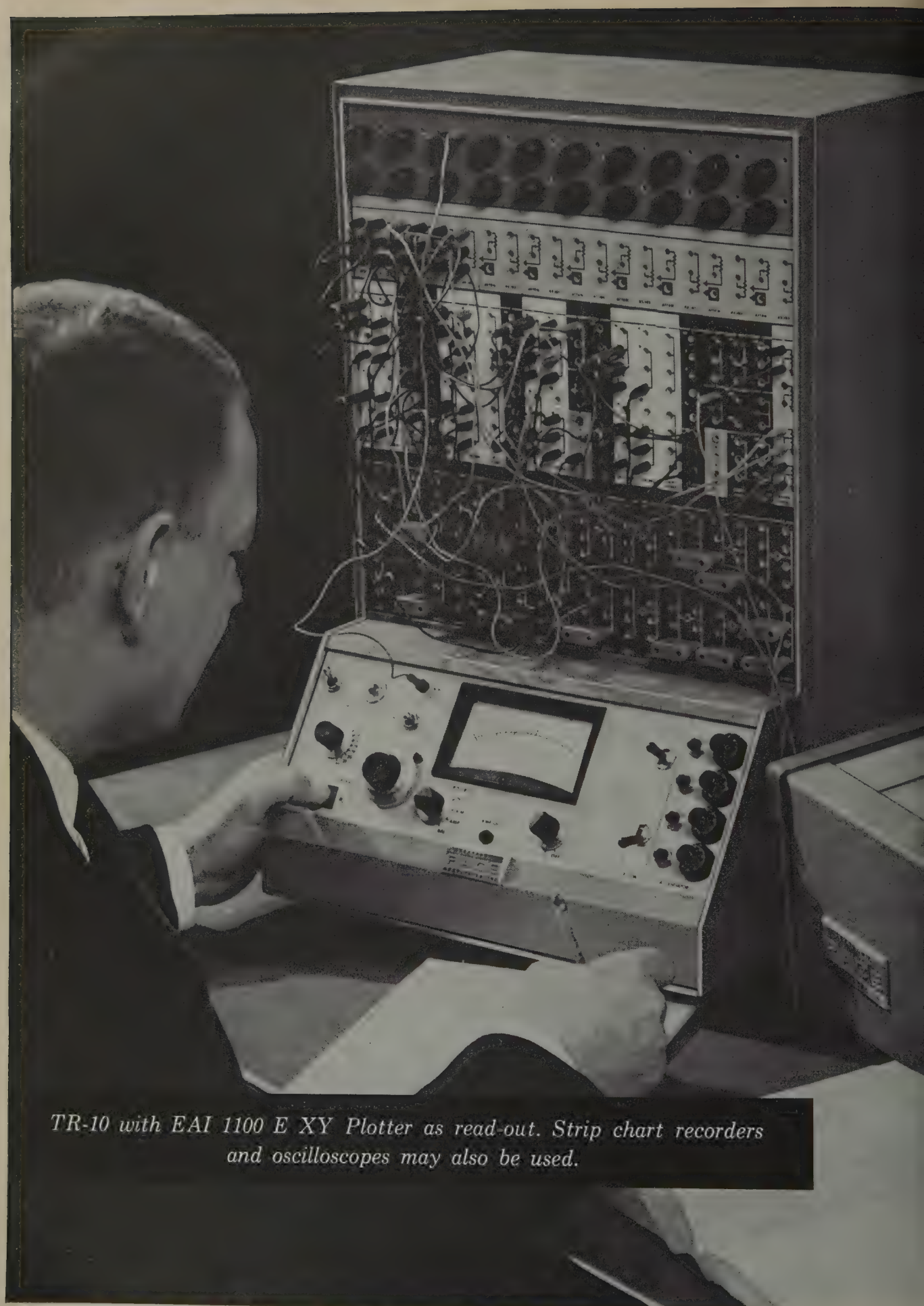

TR-10 with EAI 1100 E XY Plotter as read-out. Strip chart recorders and oscilloscopes may also be used.

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—basic model less than $4000

PACE TR-10 Eliminates Drudgery
Gives New Insight Into Engineering Problems

New transistorized computer puts the advantages of analog computation within reach of every engineer. This compact unit, 15″ x 16″ by 24″ high, is powered by 115 volts AC and can provide day-in day-out instant solution of your most vexing engineering problems. Even if you have never seen a computer before, you can learn to operate the TR-10 as easily as you learned to use a slide rule.

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Once the problem is set up on your computer, you simply turn a dial to feed in design parameters. The computer provides an instant by instant, dynamic picture of the effect of each change. You can study the inter-related effects of heat, pressure, flow, vibration, torque or any variable. And you can visually compare one with the other. You see problems in a new light – engineering data comes alive – insight into how new designs will work is obtained easier, faster. There's no need for recalculating every time you change a factor – simply turn the dial and see what effect it has on the solution.

Your "Personal Computer" for Higher Creativity

Because of its minimum size and extremely low price, the TR-10 can become your own personal analog computer. It helps to free you from routine drudgery. Permits you to gain first-hand experience with the power of analog techniques, and convert more of your time to *creative engineering.*

Test New Ideas or Designs

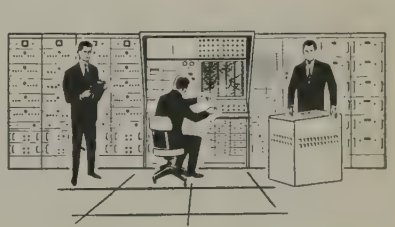
New ideas that were too costly to try before are now practical. Any possible combination of factors can be tried. You can design virtually to perfection and have a permanent, visual record of performance. All this can be done before building pilots or prototypes. As a result, "cut and try" expense is drastically reduced.

The same quality workmanship and design that has made Electronic Associates the world's leading producer of precision general purpose analog computers will be found in this new unit. Accuracy to ±.1 per cent. Modular construction allows you to select varying quantities of the following computing functions:

- Summation
- Integration
- Multiplication or Division
- Function generation
- Parameter adjustment
- Logical comparison

For complete engineering data, write for Bulletin TR-10-B

EAI systems are serving engineers throughout the world. EAI maintains Computation Centers where PACE analog equipment is available on a rental basis. Write for details.

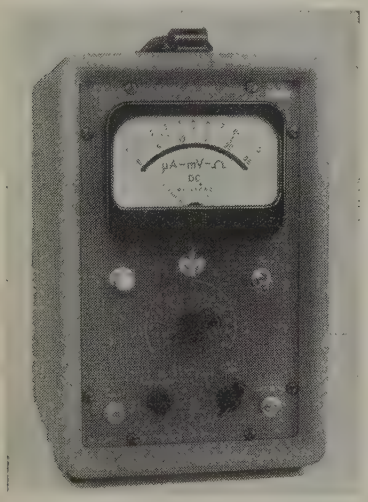


EAI ELECTRONIC ASSOCIATES, INC. ■ *Long Branch, New Jersey*

NEWS New Products

Multitester

The Model MV-77A DC Multitester manufactured by **Millivac Instruments Div., Cohu Electronics, Inc.,** P.O. Box 997, Schenectady, N. Y., combines measurement of millivolts and micro-amperes with a linear-scale ohmmeter. Measuring accuracy of this new multitester is 1 per cent of full scale on all voltage ranges, 1 per cent of full scale on all ohm measuring ranges and 3 per cent on all current ranges. The instrument has a total of 39 measuring ranges 0–1 millivolt through 0–1000 volts, 13 current ranges 0–1 micro-ampere through 0–1A, and 13 ohmmeter ranges 0–1 ohm through 0–1 megohms.



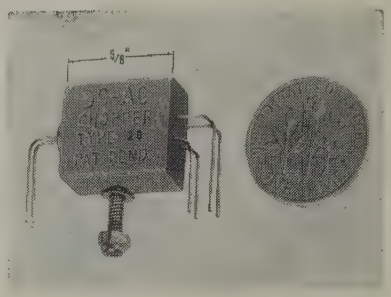
The MV-77A incorporates a new ohm-measuring circuit. Instead of measuring the current supplied to an unknown resistance by a fixed supply voltage, it measures the voltage drop produced across the unknown resistor by a constant current source. This new approach to resistance measurement problems has produced a direct-reading ohmmeter which is accurate to 1 per cent of full scale or 2 per cent of absolute reading.

The unit is housed in an armorhide case, size 12 high, 8 wide and 9 inches deep. A functional panel design and mirror scale galvanometer provide an attractive appearance. A rack-mounted model is also available.

Micro-Miniature Chopper

The manufacturer, **Rawco Instruments, Inc.,** 3527 W. Rosedale, Fort Worth 7, Texas, claims that a new concept was used to obtain micro-miniaturization of mechanical dc-ac choppers, which provides electrical characteristics comparable to units much greater in size, while exhibiting superior performance in environmental shock and vibration.

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.



Housed in a $\frac{5}{16} \times \frac{1}{2} \times \frac{5}{8}$ inch metal casement, some of its features are: a low noise level; over 2,000 hours life; −65°C to 125°C temperature range; a hermetic sealed contact closure, void of organic materials; and 150 electrical degrees minimum dwell time.

These SPDT choppers are available from stock for 6 volt–400 cps excitation and on special order, in pre-selected frequencies from 0 to 1800 cps.

For more complete information contact manufacturer.

Endevco Appoints Lovelace

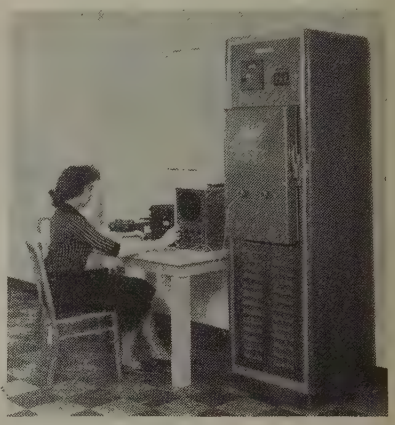
Donald E. Lovelace has been appointed Senior Project Engineer-Transducers for **Endevco Corp.,** 161 E. California St., Pasadena, Calif., electronic instrumentation firm. He is responsible for engineering development concerning the mechanical aspects of the company's products.

Before coming to Endevco Corp., Lovelace was Supervisor Engineer in the Transducers Division of Consolidated Electrodynamics. He has been aerial designer for Bill-Jack Scientific Instrument Corp., design engineer for Terrier missile at Convair, San Diego, and staff member at the University of California laboratory at Los Alamos.

Lovelace, 36, his wife and three children, live in Pasadena. He graduated from California Institute of Technology in 1948.

Portable Environmental Test

Conrad, Inc., 141 Jefferson St., Holland, Mich., has developed a brand new idea which will fulfill the test technician's requirements for a portable self-contained environmental test chamber of minimum floor space. This unit is identified as Conrad Temperature Rac 19. The unit fits into a standard 19 inch wide relay rack. The chamber is 1½ cubic feet. The unit is completely packaged as an assembly to slide into a customer's standard relay rack or can be furnished with the relay rack housing enclosure.

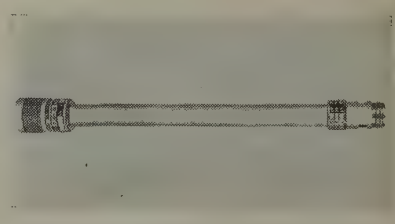


The advantages to a customer are low cost, with multiple installations along the quality control or production lines permitted. The unit fits into a row of test racks already installed, or can be placed at the end or between test benches.

The unit is supplied with indicating controller, forced air circulator, electric heating, and direct refrigeration with patented Conrad Cascade F-13–F-22 system.

Fixed Coaxial Attenuators

Stainless steel body and connectors are new features of Model 210 Fixed Coaxial Attenuators developed by **Weinschel Engineering,** 10503 Metropolitan Ave., Kensington, Md.



These attenuators are made with Weinschel Film Resistors for maximum stability under pulse power, as well as humidity and temperature cycling. Important specifications are: frequency range, 1 to 10 kmc; attenuation range, 1 to 20 db; impedance, 50 ohms; and connectors, Type N.

(Continued on page 182A)

Creative Microwave Technology

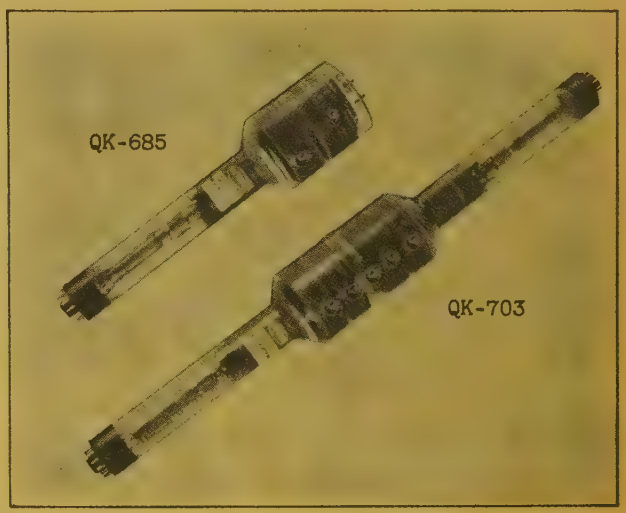
Published by Microwave and Power Tube Division, Raytheon Manufacturing Company, Waltham 54, Mass., Vol. 1, No. 4

NEW KILO-LINE RECORDING STORAGE TUBES SPECIALLY DESIGNED FOR SCAN CONVERSION

To meet the need for low-noise, high-resolution devices for frequency and scan conversion, Raytheon scientists and engineers have developed two new storage tubes: the single-gun QK-685 and the dual-gun QK-703. These tubes are now available in production quantities.

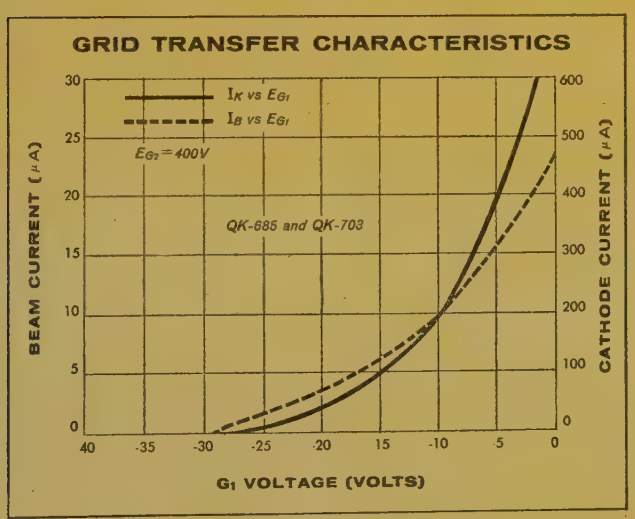
Both types incorporate a specially designed tetrode electron gun for higher resolutions — 1,000 TV lines at 50% modulation — and better control over beam cut-off than conventional triode guns. A new multiple collimating lens improves background uniformity and results in shading-to-signal ratios of less than 10%.

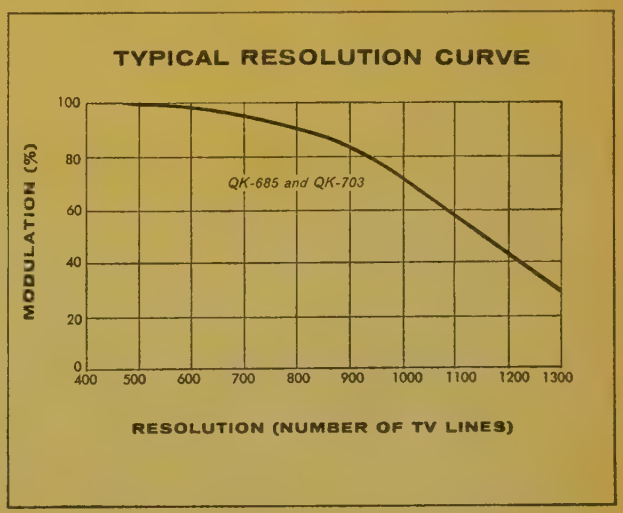
The ability of the dual-gun type to read and write simultaneously makes this tube particularly applicable to slow-down video and conversion from PPI to TV scan patterns for "Bright Display."



Typical Operating Characteristics

	QK-685 and QK-703
Anode Voltage	4,000 Vdc (Max.)
Resolving Power	
Magnetic Focus	1,000 Lines (Nom.)
Electrostatic Focus	700 Lines (Nom.)
Output Capacitance	QK-685—10 μμf (Nom.)
	QK-703—20 μμf (Nom.)
Maximum Deflection Angle	30°





You can obtain detailed application information and special development services by contacting: Microwave and Power Tube Division, Raytheon Manufacturing Company, Waltham 54, Massachusetts

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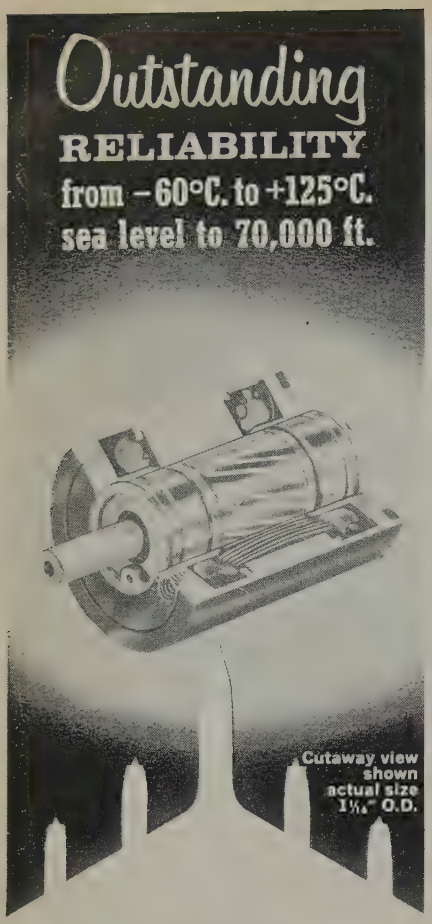

Air-Marine's new S frame motor offers outstanding reliability even at extremes of temperatures and altitude. Two models are available: the Hi-Slip which increases speed with altitude lower densities, and a CONSTANT SPEED, 11,000 rpm or 20,000 rpm.

Both models are available in 2 or 4 pole units up to 1/150 h.p. These rugged design, epoxy-potted, 400 cps induction motors are obtainable for 115 V. 10 or 208 V. 30 operation.

AIR-MARINE MOTORS, INC.

air · marine motors, inc.
AMITYVILLE, NEW YORK
LOS ANGELES, CALIF.

For further information about our complete line see page 292, I.R.E. Directory

IRE People

Tore N. Anderson (S'47–A'49–SM'55) vice-president of Airtron, Inc., a division of Litton Industries, Inc., has recently been appointed a consultant to the Secretary of Defense, serving on the Working Group on Transmission Lines of the Advisory Group on Electronic Parts. He will work with the Advisory Group on electronics research and development programs for the Army, Navy, and Air Force, with emphasis on long range planning. Headquarters for the group is at the University of Pennsylvania.

Mr. Anderson, Airtron's director of engineering, is one of the pioneers of the microwave industry. During World War II he directed work on underwater mine detectors while chief of the laboratory and test section of the Engineering Research and Development Agency, Fort Belvoir, Va. After the war he was engineer in charge of rf measurements at Electrical Testing Laboratories in New York. He became Airtron's chief engineer in 1951, a vice-president and board member in 1953 and director of engineering in 1956. Airtron is a division of Litton Industries. Inc.

❖

W. E. Ayer

P. D. Strum

Applied Technology, Inc., a new firm for sophisticated electronics systems research, development and manufacture, has been formed in Palo Alto, Calif., with **Dr. William E. Ayer** (S'42–A'47–M'50–SM'53) as president and **Peter D. Strum** (A'45–SM'55) as vice-president.

Dr. Ayer and Mr. Strum were formerly with Granger Associates, Palo Alto, where Dr. Ayer was vice-president and director of engineering and Mr. Strum was supervisory engineer. They will commence operations of their new firm May 1, 1959.

Prior to joining Granger in 1957 Mr. Ayer spent six years with Stanford University in the service-sponsored applied electronics program as project engineer, group leader, and head of the Systems Development Section. Previously he was a design engineer with Mackay Radio and Telegraph Co. in Palo Alto for six years after wartime service as a Navy radar officer.

He received the B.A., M.A., and Ph.D. degrees in electrical engineering from Stanford University. He is a registered electrical engineer in California and a member of Tau Beta Pi and Sigma Xi.

Mr. Strum was vice-president for engineering with Ewen Knight Corp., Needham, Mass. for three years, responsible for developing advances in radar receivers and radio astronomy techniques, before joining Granger in 1958. Previously he spent eight years with the Airborne Instruments Laboratory in high-performance receiver development. He also served in the Navy during World War II.

He received the B.E.E. from North Carolina State College and his M.S. in electrical engineering from Stanford University. He has written numerous papers on receiver design and radio astronomy. He is a member of Tau Beta Pi, Sigma Xi, and Eta Kappa Nu.

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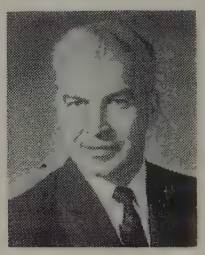


A. E. Beckers

Allen B. Du Mont Laboratories Inc. have announced the appointment of **Albert E. Beckers** (M'50) as director of engineering for tube operations.

Mr. Beckers is one of the country's leading scientists in cathode-ray and vacuum tube technology. He was born in Dortmund, Germany and holds a degree of Dipl.-Ing. in electronics and physics from the Institute of Technology in Aachen. He served as research engineer at the Research Institute of the AEG in Berlin, Germany, where he was appointed engineering manager in 1943. Soon after he became director of the Cathode-Ray Tube Division. The plant became the largest cathode-ray tube producing facility in Europe, and he was brought to this country by the U. S. Navy after World War II to carry out scientific projects for the Bureau of Ships. He then joined the Research Division of the National Union Radio Corporation.

(Continued on page 50A)

1960 RADIO ENGINEERS SHOW and IRE NATIONAL CONVENTION

March 21-24, 1960
New York, N. Y.

New York Coliseum
Waldorf Astoria Hotel

LGP-30

ROYAL PRECISION

Low in cost...

easiest to program and operate...

most in demand

Optimizes electronic component and system design

Operating from any convenient wall outlet, the LGP-30 is used right at your desk . . . helps you increase your productivity by taking the tedium out of detailed mathematical analyses. Facilitating the optimum design of electronic tubes and circuitry, servo systems, radar and antennae–the LGP-30 also serves as an important Research and Development tool in magnetic field applications, microwave and semi-conductor studies.

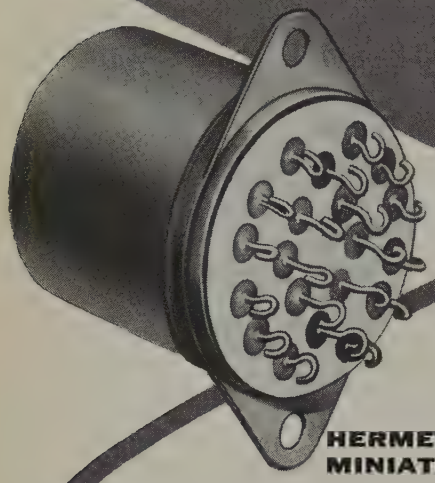
Because you operate the LGP-30 yourself, there's no waiting in line for the answers you need. Solutions are printed out in any desired alpha-numeric format – require no deciphering. Result: you optimize designs faster and easier . . . free yourself for other important creative work.

The lowest-priced complete computer your company can buy, the LGP-30 gives you memory (4096 words) and capacity comparable to computers many times its size and cost – yet it is by far the easiest to program in basic machine language. No expensive installation or air-conditioning is required. Auxiliary high-speed input-output equipment is available for system expansion.

Backed by 20 years of electronics experience, LGP-30 sales and service are available through Royal McBee offices coast-to-coast. Customer training is free. An extensive library of programs and sub-routines is available–as well as membership in an active users organization. For further information and specifications, write Royal McBee Corporation, Data Processing Division, Port Chester, N. Y. In Canada: The McBee Company, Ltd., 179 Bartley Drive, Toronto 16.

ROYAL McBEE · *data processing division*

SIMPLE DESIGN HIGH RELIABILITY ...and PRICE-RIGHT



Style 520 GENERAL PURPOSE RELAY

HERMETICALLY SEALED MINIATURE - 6 PDT

Simplicity of design and perfect performance make the Style 520 an ideal, low cost, high reliability relay for general purpose and low level circuit use.

Produced in pressurized, dust-free rooms to prevent contamination, the 520 is quality-controlled from order through production.

Meets the following specifications and drawing:

MIL-R-5757C
MIL-R-25018 (USAF)
MS24115-6 (USAF) Class B; Type II, Grade 3

Let Price stepped-up production and service solve your relay problems.

GENERAL CHARACTERISTICS
For 26.5 VOLT OPERATION

CONTACT ARRANGEMENT	Six Pole Double-Throw (6 Form C)
COIL RESISTANCE (Nominal)	240 Ohms (at 25° C)
MINIMUM CONTACT PRESSURE	25 Grams on N.C. Contacts 35 Grams on N.O. Contacts
CONTACT CAP	0.010″
OPERATING TIME	10 Milliseconds maximum at 26.5 Volts, 25° C.
DROP-OUT TIME	7 Milliseconds maximum at 26.5 Volts, 25° C.
AMBIENT TEMPERATURE RANGE	—65° C. to plus 125° C.
VIBRATION	15 G to 2,000 c.p.s.—no contact chatter, 20 G if specified.
SHOCK	50 G, 11 Milliseconds—no contact chatter.

For further details, call or write for Bulletin 12

PRICE ELECTRIC CORPORATION
Frederick, Maryland MOnument 3-5141

PRICE ELECTRIC CORP. FREDERICK, MD. HUSKY RELAYS CONTROLS

IRE People

(Continued from page 48A)

Mr. Beckers became associated with Du Mont Laboratories in 1951 as a senior engineer working on the development of special cathode-ray tubes and other display devices. In 1952 he was named manager of quality control and specifications for industrial tubes, and in 1957 was made manager of production engineering. He holds five patents in the vacuum tube field with seven others pending.

In his new position, Mr. Beckers' activities will encompass research and development of all types of cathode-ray tubes and special tube types including TV picture tubes, oscilloscope and radar indicator tubes, storage tubes, microwave tubes, multiplier phototubes, image converters, dissectors, and other photosensitive devices.

❖

Edward Birochak (A'52–M'57) has been appointed production manager for Weinschel Engineering Co., Inc., and for its subsidiary, Weinschel Engineering and Manufacturing Corp., Kensington, Maryland, specialists in precision electronic testing equipment.

E. Birochak

Prior to joining Weinschel in 1957, Mr. Birochak was employed for eight years at the Standards and Calibration Section of the Measurement Development Branch at Wright Air Development Center, Dayton, Ohio, where he was responsible for the development of microwave standards for power, impedance, attenuation, and frequency measurement. In this capacity, he gained the experience required to handle the complex problems involved in the production of similar electronic equipment.

In 1956 and 1957, he represented the Air Force on the Department of Defense Committee on Power and Impedance Measuring Equipment.

He received the B.S. degree in electrical engineering in 1949 at the University of Kentucky and has done graduate work at Ohio State University. He is a member of the Professional Groups on Instrumentation and Microwave Theory and Technique of the IRE.

❖

Dr. John T. Bolljahn (A'43–SM'53–F'57), one of the West Coast's outstanding young electronic research executives, will leave his post as assistant director of engineering research at Stanford Research Institute to become executive vice-president of Granger Associates.

Dr. Bolljahn joined Stanford Research

(Continued on page 52A)

NEW HIGH-RELIABILITY TANTALUM CAPACITOR SERIES

tan-TI-cap*

SOLID TANTALUM CAPACITORS

ACTUAL SIZE CASE STYLES

SRM SERIES

125°C operation • standard ±10% tolerance

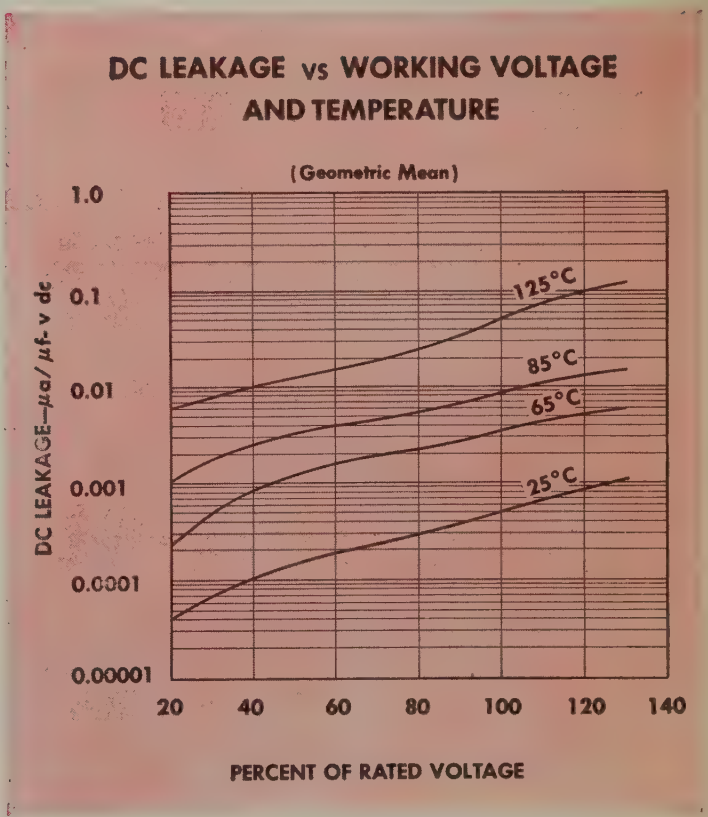
Now, premium performance solid tantalum capacitors to fill your highest reliability requirements!

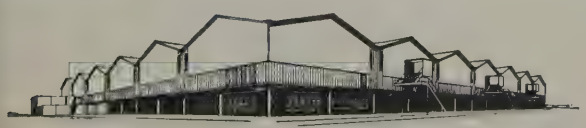
134 ratings from 1-330 μf, 6-35 v

Exceeding all existing MIL specs over a full range of industry-standard ratings and case sizes, the subminiature SRM series features . . . new low dc leakage limits and long operating and storage life . . . standard ± 10% tolerance . . . operation from −80°C to + 125°C . . . ruggedized construction . . . reverse voltage capability . . . nominal voltage derating required at 125°C. TI's advanced processing techniques and 100% testing of pre-aged units assure SRM capacitors to the most exacting reliability standards.

*Trademark of Texas Instruments Incorporated

Contact your nearest TI sales office today for delivery information and your copy of the 12-page bulletin listing specifications of all 134 ratings.





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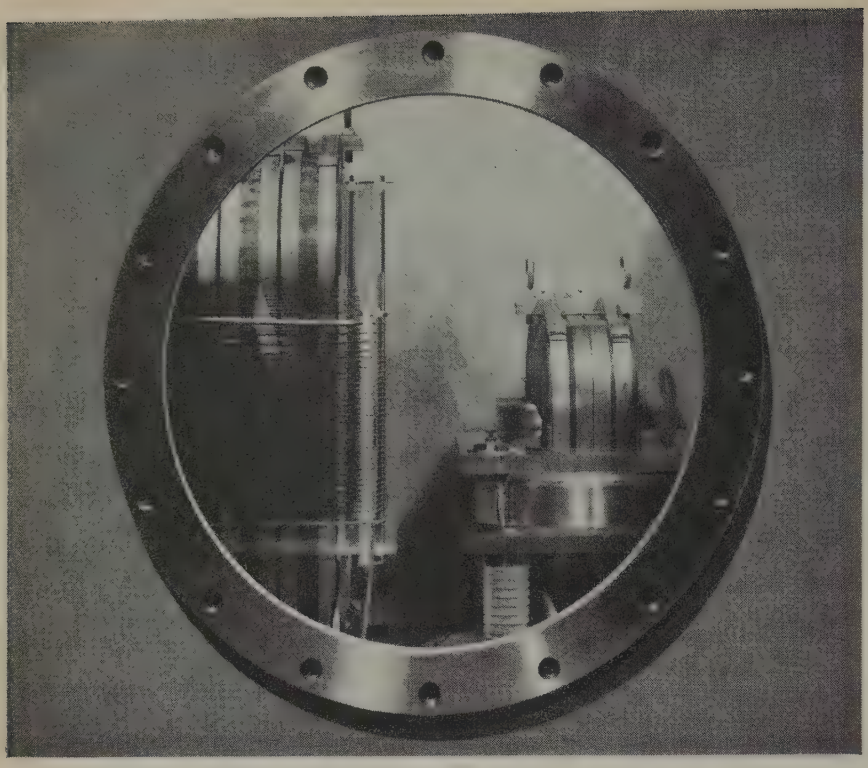


gun port

You are looking into the mounting port of an injection gun type tube, a high voltage transformer consisting of the monofilar pulse transformer visible at the left and the filament transformer at right. Specifications of these components are given below; additional information on this and similar pulse equipment available on request.

PULSE TRANSFORMER Catalog No. 819

OUTPUT PARAMETERS	
Peak E, KV:	250
Peak I, Amps:	250
Peak P, MW:	62.5
Load Z, Ohms:	1,000
Pulse Width, μs:	5 nominal (1—25 μs range)
Rise Time, μs:	1 (5% to 95%)
Droop at Max. Pulse Width:	5% at 5 μsec
Overshoot:	5% max.
Backswing:	30%, max.
Repetition Rate:	1 to 15 pps
Avg. Power, Watts:	25,000 max.
Duty Ratio:	.004 max.
INPUT PARAMETERS	
Turns Ratio Pri/Sec:	1/4.4
Peak E, KV:	57
Peak I, Amps:	1,100
Impedance, Ohms:	52
GENERAL	
Type of Sec. Winding	Monofilar

FILAMENT TRANSFORMER Catalog No. 923

OUTPUT PARAMETERS	
Voltage:	100 volts rms
Current:	100 amps nominal, 150 max.
Power:	10 KVA nominal, 15 KVA max.
Insulation:	250 KV pulse width at 25 μs
INPUT PARAMETERS	
Frequency:	60 cps
Voltage:	220 volts rms, 1ø
GENERAL	
Type of Secondary Winding:	Copper Strip Helix

PHYSICAL DESCRIPTION

Size: 40" x 35" x 28"
Weight: 1200 lbs. approx., exclusive of weight of oil

carad corp.

For additional information, write:
carad corporation
2850 Bay Road
Redwood City, California
EMerson 8-2969

IRE People

(Continued from page 50A)

Institute in 1949 after receiving his Ph.D. in electrical engineering at the University of California. He did his undergraduate work in electrical engineering at California also and was associated with the university's Navy Electronics Laboratory for three years while studying for his doctorate.

At SRI he was engaged in research programs concerned with antennas, propagation, microwave components improvement, aircraft communication and navigation systems, missile tracking systems, and weapon systems studies.

Promoted to assistant director of the Engineering Division in July of 1956, he was made responsible for activities of SRI's Electromagnetics Laboratory, Radio Systems Laboratory, Communication and Propagation Laboratory, and Weapons Systems Laboratory.

During World War II he served as a radio engineer in the Naval Research Laboratory, Washington, D. C., acting as a leader of the Antenna Group in the Aircraft Section, Radio Division. Prior to the Allied invasion of Europe he spent several months as a member of a team responsible for designing special countermeasure equipment for surface vessels operating out of Great Britain and North Africa.

He is a newly elected Fellow of the IRE and has served as a member of the National Administrative Committee of the IRE Professional Group on Antennas and Propagation. He is a past chairman of the editorial board of "The Grid," monthly publication of the San Francisco Section of the IRE, and is currently a member of the Institute's Editorial Review Committee. He is presently serving as vice-chairman of the technical program committee for WESCON-1959.

His memberships also include Sigma Xi, Eta Kappa Nu, Tau Beta Pi and the Armed Forces Communications and Electronics Association.

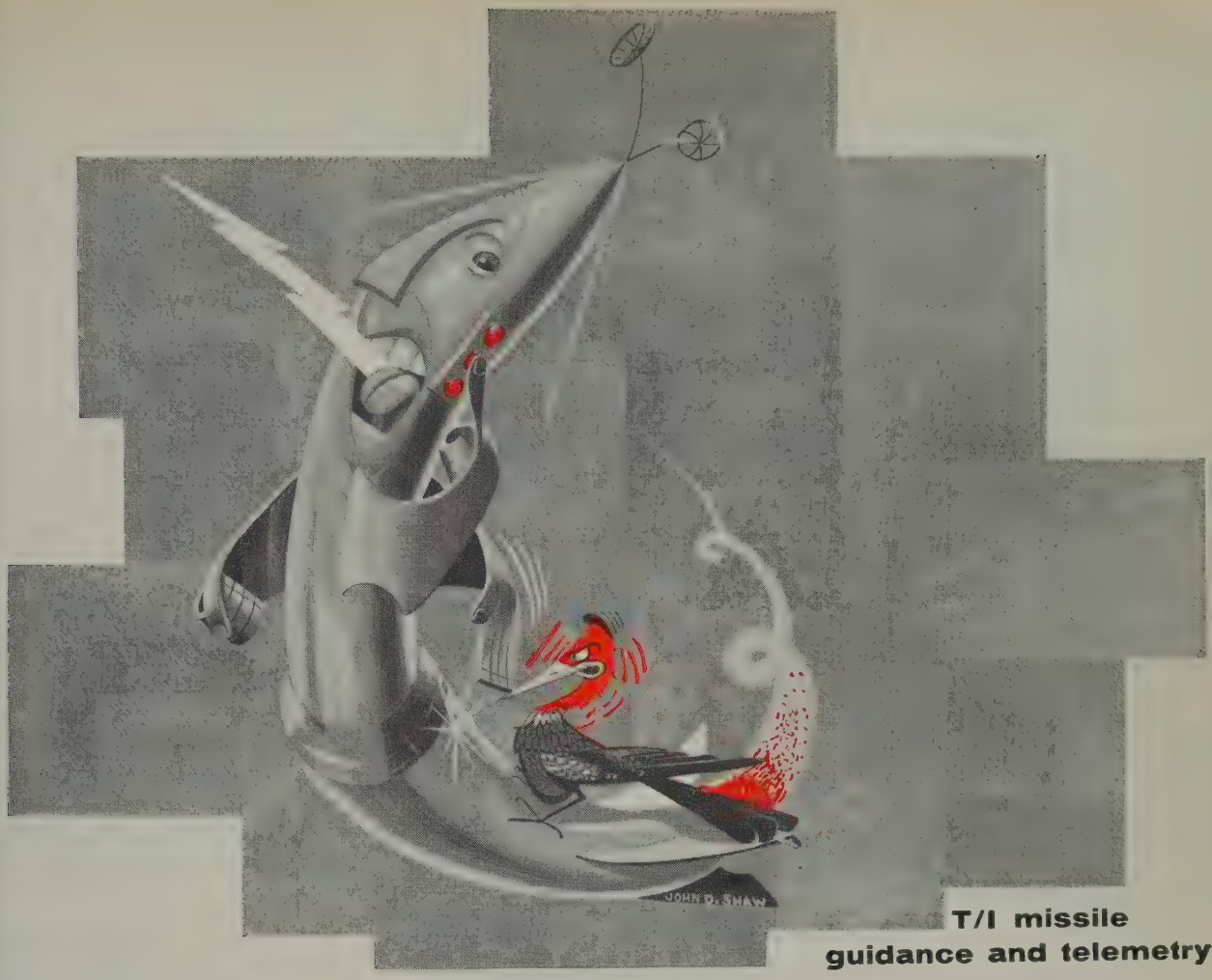
❖

F. Beaumont Bramhall (M'42–SM'43), a leading expert in telegraph and data transmission, has joined Lenkurt Electric Company as an engineering consultant. Mr. Bramhall, who has just completed 39 years with Western Union Telegraph Company, will assist with product planning and marketing activities for Lenkurt at its headquarters plant in San Carlos, Calif.

F. B. BRAMHALL

After one year as a radio engineer and operator with Marconi, he began his career with Western Union as an engineer in communication development and research. While in charge of that company's research laboratory he pioneered in fre-

(Continued on page 54A)



T/I missile guidance and telemetry

BEEPS WITH A HIGH IQ

...for missile sensing, guiding and telemetering

Electronic signals that report the truth, the whole truth, and nothing but . . . wring the best performance from missile systems. By pushing beyond known capabilities in sensitivity and accuracy, Texas Instruments is producing "high IQ" systems and equipments for a dozen guided vehicles used in every basic mission: air-to-air, air-to-surface, surface-to-air, surface-to-surface — IRBM and ICBM—plus drone sensors and satellite instrumentation. TI exceeds tough specs against tight deadlines, regularly . . . specs asking solutions to problems never posed before. For detailed discussion, cleared personnel please write or call: SERVICE ENGINEERING DEPARTMENT.

RESEARCH/DESIGN/DEVELOPMENT/MANUFACTURING of systems for: *Air traffic control* • *Airborne early warning* • *Antimissile* • *Antisubmarine warfare* • *Attack control* • *Countermeasures* • *Missile systems Navigation* • *Reconnaissance* • *Space electronics; and on detector cells, engine instruments, infrared, intercom, microwave, optics, radar, sonar, telemetry, time standards, timers, transformers and other precision devices.*

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EASTERN FIELD ENGINEERS FOR:

ADVANCED ELECTRONICS • ALLISON LABORATORIES • BRUSH INSTRUMENTS • CARDINAL INSTRUMENTS • DEMOLAB • DONNER SCIENTIFIC CO • ELECTRO INSTRUMENTS • ELECTRO-PULSE • EMPIRE DEVICES PRODUCTS • HOLT INSTRUMENT LABORATORIES • LEVINTHAL ELECTRONIC PRODUCTS • MAGNETICS RESEARCH • NARDA MICROWAVE • NJE • SYSTRON WAYNE-KERR LABORATORIES.

* *Midnight oil and coffee are consumed by the gallon in the conference-lecture hall of our new Mt. Vernon main office. We estimate that every BA field engineer receives the equivalent of a college semester of graduate training each year. Factory experts, technical managers and selected professional consultants lecture to our entire field staff in frequent, scheduled "head-sessions". One more reason to "Get the Burlingame Habit".*

(Continued from page 52A)

quency-modulation telegraphy and directed the development and design of equipment for landline carrier telephone and telegraph transmission. He also directed developments resulting in microwave radio for domestic telegraphy frequency-division multiplex equipment for microwave radio, facsimile transmission systems and a number of other telecommunications innovations. He has many patents to his credit and is the author of a number of technical papers, particularly in the fields of frequency-division multiplexing, modulation, and digital data transmission. In 1957 he received the F.E. d'Humy Award from Western Union "for contributions to the art of frequency-modulated carrier telecommunication and for technical direction leading to its wide adoption."

Mr. Bramhall received his B.S. degree in electrical engineering from Pennsylvania State University and did graduate study in mathematics and physics at Columbia University.

❖

Thomas L. Enderle (SM'58), of San Antonio, Texas, was recently cited by Lt. Gen. George W. Mundy, Commandant of the Industrial College of the Armed Forces, Washington, D. C., for having successfully completed the college's correspondence course.

T. L. Enderle

The course entitled "The Economics of National Security," is based on the 10-month resident course conducted for selected senior officers of the military services as well as officials of the civilian governmental agencies.

Mr. Enderle is Logistics Officer, Electronics Warfare, Headquarters, San Antonio Air Materiel Area, Directorate of LSM, Kelly AFB, Texas. He is a member of the Institute of Aeronautical Sciences.

❖

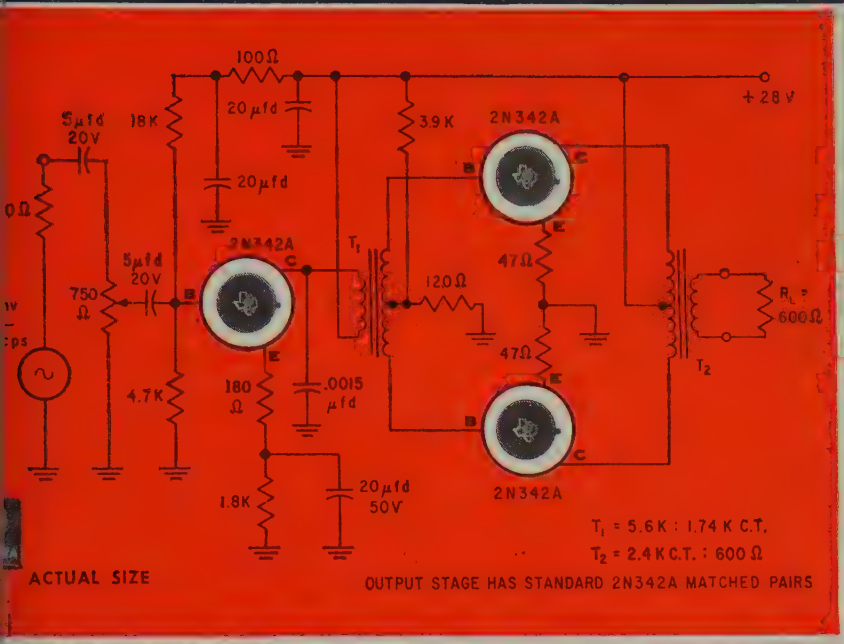
At the spring meeting of the Optical Society of America, April 2–4, **Dr. Gerald W. Farnell** (S'51–A'53), associate professor of electrical engineering at McGill University in Montreal, Canada, was awarded the $250 First Prize for the best contributed paper presented in 1958 before the society and published in the *Journal of the Optical Society of America*. The paper was entitled "Axial Phase Anomaly for Microwave Lenses."

A native of Toronto, Dr. Farnell received the B.S. degree in electrical engineering from the University of Toronto, the M.S. degree from M.I.T., and the

(Continued on page 56A)

TI Silicon Transistor Application Note

TRANSISTORIZED INTERCOM EXCEEDS MIL-E-5272B SPECS



CIRCUIT SPECIFICATIONS

150-mw output from -55°C to 100°C at less than 10% harmonic distortion over frequency range

Frequency response @ 25°C stable within ±2 db of 1000 cps 100 mw reference level from 200 to 8000 cps

Frequency response @ -55°C and 100°C within ±3 db of 25°C frequency response

Less than 3-db gain variation @ -55°C and 100°C compared to 25°C measurement

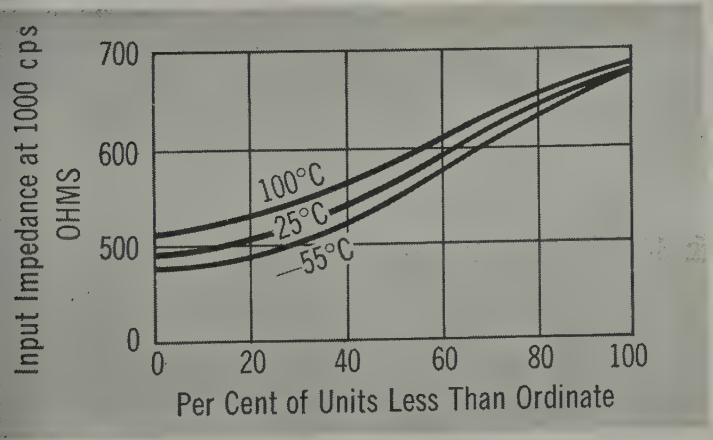
LOUD AND CLEAR AT 100°C!

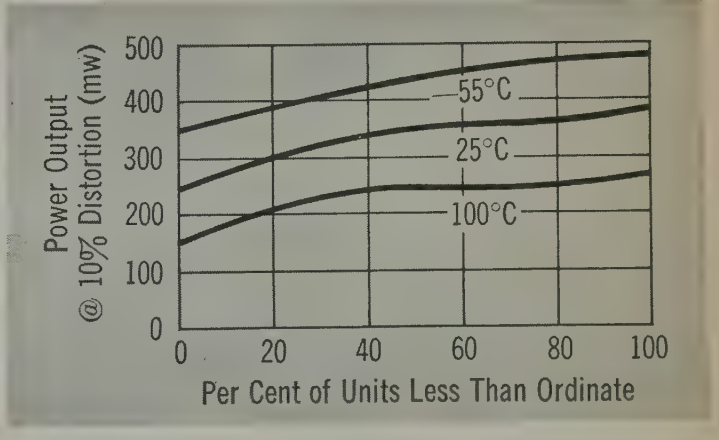
. . . with TI 2N342A silicon transistors from stock

You can satisfy the 71°C equipment requirements of MIL-E-5272B at 100°C with the intercom amplifier circuit shown above — using TI 2N342A silicon transistors with . . . guaranteed 3-to-1 linear beta characteristics . . . 85-v collector-to-emitter breakdown, giving a wide safety range with 28-v aircraft supplies . . . plus dissipation capability of 1 watt at 25°C and 200 mw at 125°C.

The newest addition to the *use-proved* TI 2N339 series introduced in 1957, this medium-power unit carries the full-year TI guarantee and is immediately available *off-the-shelf* from all TI distributors in 1-249 quantities. For production quantities, contact your nearest TI sales office.

TYPICAL INTERCOM AMPLIFIER PERFORMANCE CHARACTERISTICS USING 2N342A TRANSISTORS





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DALLAS, TEXAS

NOW... first electrostatic generators for industrial use that can give several kilowatts at up to 600,000 volts dc

The complete line of "Sames" electrostatic generators—the first practical industrial electrostatic power supplies—are now available in the U.S. from Sorensen & Company. They supply from 50 to 600 kilovolts dc at substantial amounts of power (2400 watts for the 600 kv model).

The Sames generators (so-called from their manufacturer, Societe Anonyme de Machines Electrostatiques, Grenoble, France) are extremely compact and safe compared to transformer-rectifier-filter-type supplies in similar kilovolt ranges. The electrostatic generators are available in highly stabilized models supplying 50, 100, 150 and 600 kilovolts that are particularly suitable for electron-microscopy and many critical nuclear physics applications. Medium stability models with outputs of 50, 80, 100, 140, 150, 250, 300, and 600 kilovolts, have found wide application in Europe for testing cable insulation, alternator windings and other dielectrics, electrostatic flocking, painting and particle precipitation, electron and nuclear particle accelerators and similar applications.

Write for complete details on Sames electrostatic generators to Sorensen & Company, Richards Avenue, South Norwalk, Conn. s.36

HIGH VOLTAGE

SAMES 600-kilovolt electrostatic generator with control panel and electronic unit.

SORENSEN & COMPANY, INC.
Richards Avenue, South Norwalk, Conn.

WIDEST LINE OF CONTROLLED-POWER EQUIPMENT FOR RESEARCH AND INDUSTRY

In Europe, contact Sorensen-Ardag, Zurich, Switzerland. **In Western Canada,** ARVA. **In Eastern Canada,** Bayly Engineering, Ltd. **In Mexico,** Electro Labs, S.A., Mexico City.

IRE People

(Continued from page 54A)

Ph.D. degree from McGill University. While at M.I.T. he worked on the design of multichannel radio telemetering equipment for guided missiles.

His interest in microwave optics was inspired by studies of the application of analog computer techniques to microwave lens calculations. This interest led to an investigation of the phase distribution in the region of a focus.

At present he is concerned also with the design of low-noise paramagnetic amplifiers. A member of the faculty of McGill University in Montreal since 1950, he is both in the electrical engineering department and on the research staff of the Eaton Electronics Laboratory of the Department of Physics.

He is a member of Sigma Xi and the Canadian Association of University Teachers.

❖

George H. Gage (M'50) has been recently appointed manager of product planning for CBS-Hytron, a Division of Columbia Broadcasting System, Inc. Prior to this appointment Mr. Gage was commercial engineer of internal sales with the General Electric Company.

G. H. GAGE

He received the B.S. degree in electrical engineering from Rensselaer Polytechnic Institute in 1948 and since then has accumulated broad tube application experience in the industrial, military, and entertainment fields.

He was a contributing editor to McGraw-Hill's "Industrial Electronics Handbook" and also a member of the EIA committees on Television Tube Ratings and Pulse Ratings. He has spoken at numerous meetings and conferences including those sponsored by the IRE, AIA and RETMA.

He is a member of Eta Kappa Nu, Tau Beta Pi, and Sigma Xi.

❖

Robert E. Galloway, Sr. (Major, USA Ret.) (M'54–SM'57) has been named chief engineer for Cunningham Electronic Selecting Scale Co., Augusta, Georgia, with responsibility for coordinating design activities of a patented weighing and classifying apparatus. He is one of three partners of this company, which will manufacture and distribute the device which electronically measures, by weight and within adopted parameters, manufactured articles which require precision weighing before being placed on their respective markets.

Mr. Galloway is a member of the Institute of the Aeronautical Science and the Society of American Military Engineers.

❖

(Continued on page 58A)

ESC delay lines take off with America's talking satellite

On December 18, 1958, the world entered a new era of communications with the successful orbiting of an Atlas ICBM—the Talking Satellite that broadcast President Dwight D. Eisenhower's Christmas message to the world. Circling the earth at a speed of more than 17,000 mph, the Talking Satellite repeated the President's message, erased it, and received and rebroadcast new messages in both voice and code.

ESC Corporation is justifiably proud that its delay lines were selected to aid in this electrifying triumph for America and her electronics industry. Especially designed by ESC, these delay lines were used in the timing sequence for propulsion, the guidance system and the telemetering system.

As America's largest manufacturer of custom-built and stock delay lines, ESC has continually met the responsibility of leadership by providing virtually every type of delay line needed by defense and industry. If you have a delay line problem, let ESC's design staff suggest a custom-built answer.

WRITE TODAY FOR COMPLETE TECHNICAL DATA.

exceptional employment opportunities for engineers experienced in computer components . . . excellent profit-sharing plan.

ESC CORPORATION 534 BERGEN BOULEVARD, PALISADES PARK, NEW JERSEY

Distributed constant delay lines • Lumped-constant delay lines • Variable delay networks • Continuously variable delay lines • Pushbutton decade delay lines • Shift registers • Pulse transformers • Medium and low-power transformers • Filters of all types • Pulse forming networks • Miniature plug-in encapsulated circuit assemblies

A Logical Deduction

Because ordinary magnetically-regulated power supplies are **too sluggish** to handle load and line transients,

Because NJE refused to be satisfied with such performance, and developed, back in 1956, a **fundamentally superior circuit,**

Because this thoroughly proven circuit uses the speed and power-gain of a transistor amplifier to force rapid response from the magnetic amplifier,

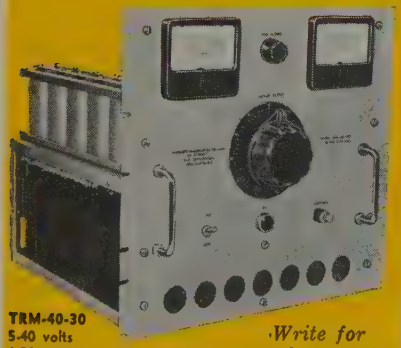
Because the transistors are never in the power path, but handle low-level signals only,

Because this transistor-magnetic—"TRM"—circuit retains the reliability and economy of magnetically-regulated supplies, but greatly improves speed of response (15 millisec. typical) widens operating range (8:1 typical) and tightens regulation (0.1% typical),

Because TRM supplies can be "zero-lagged" against line and load transients,

It follows that NJE TRM is your **best buy** in a magnetically-regulated power supply!

QED... choose NJE



TRM-40-30
5-40 volts
0-30 amperes

Write for complete catalog

MODEL NUMBER	OUTPUT RANGE VOLTS	AMPERES
TRM-28-30	24-32	0-30
TRM-28-60	24-32	0-60
TRM-28-120	24-32	0-120
TRM-40-15	5-40	0-15
TRM-40-30	5-40	0-30
TRM-40-60	5-40	0-60
TRM-40-120	5-40	0-120
TRM-80-7.5	10-80	0-7.5
TRM-80-15	10-80	0-15
TRM-80-30	10-80	0-30
TRM-80-60	10-80	0-60
TRM-160-7.5	20-160	0-7.5
TRM-160-15	20-160	0-15
TRM-160-30	20-160	0-30

NJE CORPORATION
345 Carnegie Avenue, Kenilworth, New Jersey
CH 1-1500 TWX - Roselle, N. J. 51 FAX - FFP

IRE People

(Continued from page 56A)

Lenkurt Electric Company has announced the promotion of **Thomas A. Combellick** (A'52–SM'56) to chief engineer in the company's Military Division. Mr. Combellick assumes this position after four years with Lenkurt during which time he has headed departments concerned with communications engineering, radio and military transmission, and product standards. His most recent assignment has been as manager of Lenkurt's Washington, D. C. office.

T. A. COMBELLICK

Previously he was in charge of Westinghouse's microwave system development, and before that he was with Western Electric as a project engineer on the manufacture and test of tubes for the TD-2 microwave system.

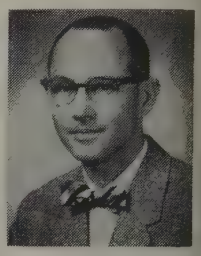
He is a graduate of Hampden-Sydney College in Virginia and has done graduate study at Harvard University and Massachusetts Institute of Technology. He is an Associate Member of the American Institute of Electrical Engineers and serves as a member of the AIEE committee on radio systems.

❖

The meeting of the judges of the Hanau Award of Germany was held in Frankfurt/M on December 12, 1958 under the chair of Prof. Dr. B. Rajewski of the Max Plank Institute. In this meeting a furtherance award of DM 1000.00 was bestowed on the paper entitled "Normal Gratings" by **Reinhold Gerharz** (A'52–M'57–SM'57). Mr. Gerharz is a resident physicist at the Office of Physical Research of the United States Weather Bureau.

❖

Paul S. Goodwin (S'42–A'44–M'45–SM'52) has joined Ling Electronics, Inc. as special staff assistant to the vice-president and chief engineer, with duties as senior project engineer for underwater sound systems.



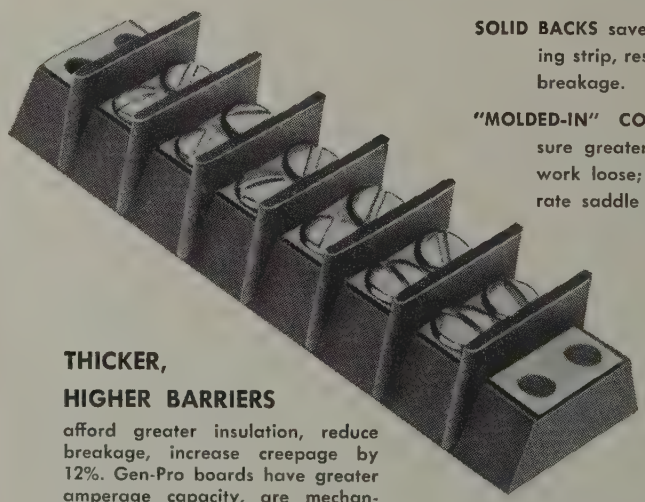
P. S. GOODWIN

Mr. Goodwin comes to the Ling engineering staff from Applied Research Laboratories where for the past five years he has been engineering division manager and manager of the analytical systems division. His previous ex-

(Continued on page 60A)

new GEN-PRO®

SOLID-BLOCK TERMINAL BOARDS



SOLID BACKS save cost of insulating strip, resist moisture and breakage.

"MOLDED-IN" CONDUCTORS assure greater capacity, can't work loose; eliminate separate saddle plates.

THICKER, HIGHER BARRIERS afford greater insulation, reduce breakage, increase creepage by 12%. Gen-Pro boards have greater amperage capacity, are mechanically and electrically interchangeable with other boards. Also available with molding compound PER MIL-14E. Competitively priced. Immediate delivery.

Series 440 Illustrated

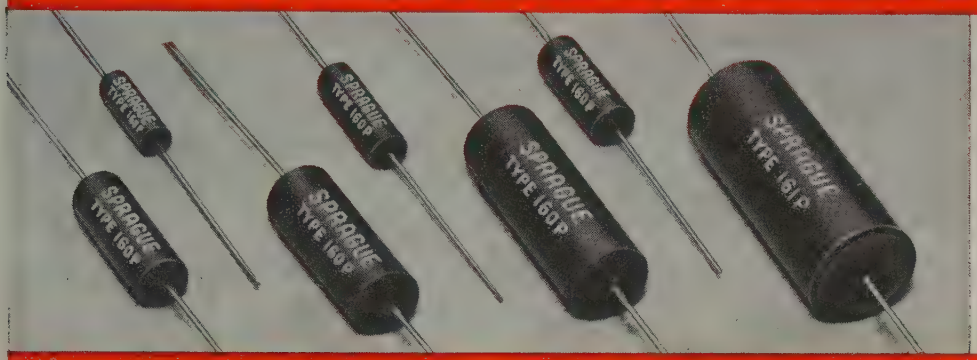
WRITE TODAY for bulletin illustrating types in stock with specifications and list of lugs available.

GENERAL PRODUCTS CORPORATION
Over 25 Years of Quality Molding
UNION SPRINGS, NEW YORK TWX No. 169

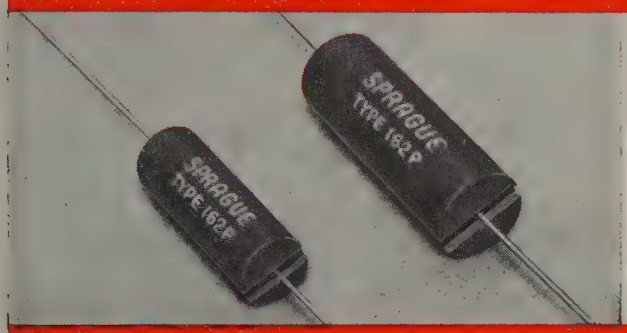
DIFILM® DUAL DIELECTRIC

gives new BLACK BEAUTY® series of small, low-cost capacitors outstanding performance characteristics

- withstand 105C operation with no voltage derating
- moderate capacitance change with temperature
- excellent retrace under temperature cycling
- superior long-term capacitance stability
- very high insulation resistance



NEW!... DIFILM Type 160P fully-molded case and Type 161P pre-molded case capacitors in 5/16" to 1" diameters for general commercial and entertainment electronics.



NEW!... DIFILM Type 162P slotted-base multi-purpose molded case capacitors for auto radios and other severe vibration applications. Slot prevents collection of moisture around leads when capacitor is end-mounted against chassis.

• New DIFILM Black Beauty Capacitors represent a basic advance in paper tubular capacitor design. DIFILM Capacitors combine the proven long life of paper capacitors with the effective moisture protection of plastic capacitors . . . by using a *dual dielectric of both cellulose and polyester film that's superior to all others for small, yet low cost, capacitors.*

• Just check the characteristics listed above. This overall performance is fully protected by HCX®, an exclusive Sprague hydrocarbon material which impregnates the windings, filling all voids and pinholes before it polymerizes. The result is a solid rock-hard capacitor section, further protected by an outer molding of humidity-resistant phenolic. *These capacitors are designed for operating temperatures ranging up to 105°C (221°F) . . . at high humidity levels . . . without voltage derating!*

For complete specifications on DIFILM Black Beauty Capacitors, write for Bulletin 2025 to Technical Literature Section, Sprague Electric Company, 235 Marshall Street, North Adams, Massachusetts.

SPRAGUE®
THE MARK OF RELIABILITY

SPRAGUE COMPONENTS:

CAPACITORS • RESISTORS • MAGNETIC COMPONENTS • TRANSISTORS • INTERFERENCE FILTERS • PULSE NETWORKS • HIGH TEMPERATURE MAGNET WIRE • CERAMIC-BASE PRINTED NETWORKS • PACKAGED COMPONENT ASSEMBLIES

SOME NOT SO PLEASANT VARIATIONS

"Variety is the spice of life", a canned-food manufacturer tells us. This holds true in a great many fields. In mathematics, few studies are as fascinating as the calculus of variations. In music, what could be more pleasant than Brahms' "Variations on a Theme by Haydn"?

But in electricity, equipment designers are often faced with some not so pleasant variations in line voltage. Neither mathematics nor music is of much help here.

The best solution to date is a Raytheon custom magnetic-amplifier voltage regulator which, in a weather radar, successfully stabilizes single-phase line variations ranging from 105 to 125 volts, and holds them to within ±1% of 115 volts. This is in spite of the fact that line frequency variations are as much as ±5%, and ambients from −45 F to +45 F.

Raytheon engineers have solved a variety of such voltage regulation problems. Why not tell them yours? Simply contact:

VOLTAGE REGULATOR MAN
Raytheon Manufacturing Company
Magnetic Components Product Dept.
Section 6120
Waltham 54, Massachusetts

RAYTHEON

Excellence in Electronics

IRE People

(Continued from page 58A)

perience also includes six years as development engineer on scientific instruments for Consolidated Electrodynamics Corporation and three years with Sperry Gyroscope Company, where he worked on airborne radar projects.

He holds a B.A. degree in electrical engineering from Stanford University as well as an M.A. degree in communications engineering and an electrical Engineer's degree in administration from Stanford.

❖

James M. Hall (M'57) has been named chief engineer of the Semiconductor Department of P. R. Mallory and Co., Inc. with headquarters in Indianapolis, Indiana. He will direct the engineering activities of the Semiconductor Department which produces silicon rectifiers and other semiconductor devices.

J. M. HALL

Mr. Hall is an electronic engineering graduate of Evansville College and was previously a section engineer in semiconductor engineering for the Mallory Company. He came to Mallory in 1956 from Minneapolis Honeywell where he was engaged in transistor engineering.

❖

Byron L. Havens (SM'46), resident manager of the Mohansic Research Laboratory of the International Business Machines Corporation in Yorktown, N. Y., has been appointed technical director of the recently created Advanced Product Development Division of IBM. In his new post, Mr. Havens will be in charge of engineering and technical activities, but he will also continue his duties as resident manager of the Mohansic Laboratory and manager of physical systems research.

B. L. HAVENS

Last year, Mr. Havens participated in an experiment conducted at the IBM Watson Laboratory in New York City, to confirm a special postulate of Einstein's theory of relativity which states that the speed of light or radio waves is independent of its frame of reference or of the motion of the light itself. Mr. Havens, working with two other scientists, measured the change in frequency of radio waves radiating from a beam of "excited" ammonia molecules over a period of one day. Molecular wave frequencies were meas-

(Continued on page 63A)

NEW ECONOMY OF CIRCUIT DESIGN with new NPN power transistors

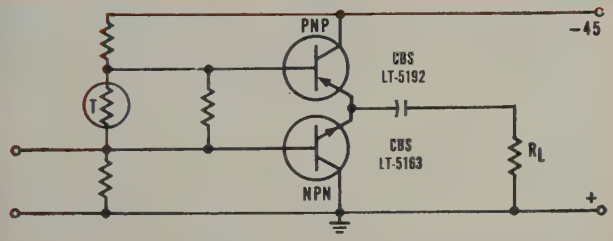
. . . in complementary push-pull circuits

These new NPN transistors in the complementary push-pull circuit eliminate input and output transformers with many resulting advantages:

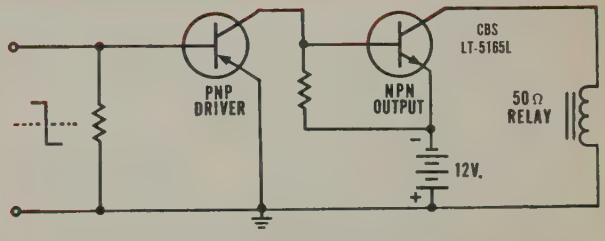
1. Economy. 2. Miniaturization. 3. Improved frequency response. 4. Ease of applying negative feedback.

. . . in complementary cascade circuits

CBS NPN power transistors are also intended for single-ended cascade output circuits, and three types are designed for use with inductive loads such as output transformers, motors and relays. The simplified direct-coupled circuits permit economies through elimination of components.



COMPLEMENTARY CLASS B AMPLIFIER



DIRECT-COUPLED COMPLEMENTARY CONTROL AMPLIFIER

FIRST COMPREHENSIVE LINE OF NPN POWER TRANSISTORS

Type	Max. W Diss. (25°C Ambient*)	Max. V_{CBO}	Max. V_{CES}	Min. h_{FE} (I_C=0.5A)	Max. Thermal Res. °C/W	Similar PNP Types
FOR RESISTIVE-LOAD CIRCUITS						
2N326	20	35	35†	30	3	2N325
LT-5165	20	35	30#	30	3	LT-5191
LT-5163	20	60	45#	30	3	LT-5192
LT-5164	20	80	60#	30	3	LT-5193
FOR INDUCTIVE-LOAD CIRCUITS						
LT-5165L	20	35	30φ	30	3	LT-5191L
LT-5163L	20	60	45φ	30	3	LT-5192L
LT-5164L	20	80	60φ	30	3	LT-5193L

All seven types have: Max. collector current, 3 amps; storage temperature, −65 to +85°C; avg. cutoff frequency, 150 kc. *Adequate heat sink required.
†I_{CES} = 1 ma. max. #I_{CES} = 10 ma. φI_{CES} = 300 ma.

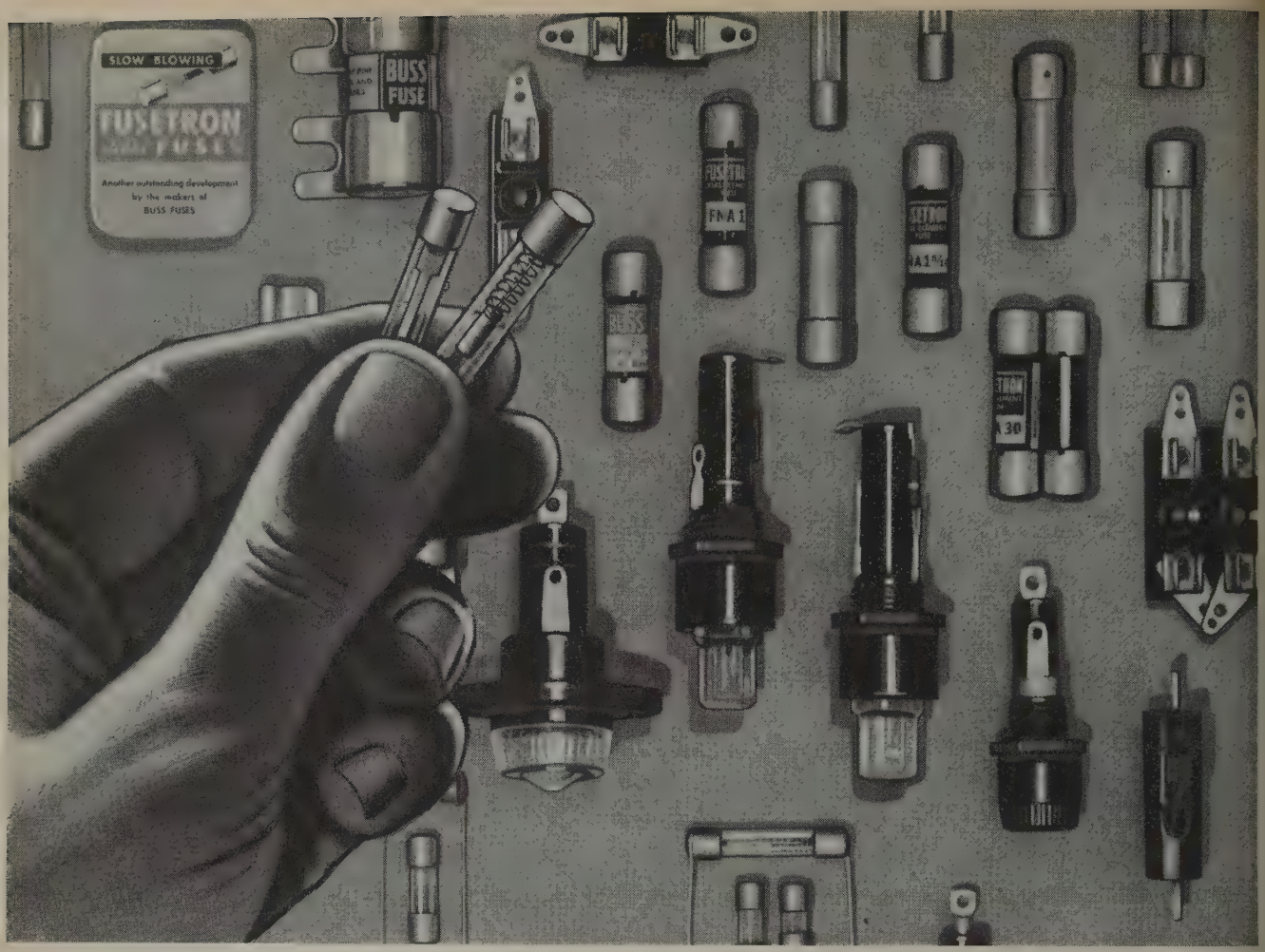
New design economies in complementary push-pull and cascade circuits are made possible by these CBS NPN power transistors. They feature high voltages . . . up to 80 volts. Their proven reliability (they meet the MIL-19500A specification) is what you might expect from specialists in reliable NPN switching and PNP power transistors. Check the typical circuits and abbreviated data for this versatile and comprehensive line. Write for complete technical Bulletin E-332 . . . and, if you wish, for Bulletin E-348 on CBS PNP power transistors for complementary circuits.

More reliable products through Advanced-Engineering

CBS semiconductors®

Sales Offices: **Lowell, Mass.,** 900 Chelmsford Street, GLenview 4-0446 • **Newark, N. J.,** 32 Green St., MArket 3-5832 • **Melrose Park, Ill.,** 1990 N. Mannheim Rd., EStebrook 9-2100 **Los Angeles, Calif.,** 2120 S. Garfield Ave., RAymond 3-9081

CBS ELECTRONICS, Semiconductor Operations
A Division of Columbia Broadcasting System, Inc.



For Every Electrical Protection Requirement . . .

there's a safe and dependable BUSS or FUSETRON Fuse!

BUSS fuse engineers have consistently pioneered the development of new fuses to keep pace with the demands of the Electronic Industry. Today, the complete line includes:

Single-element fuses for circuits where quick-blowing is needed;—or single-element fuses for normal circuit protection;—or dual-element, slow-blowing fuses for circuits where harmless current surges occur;—or indicating fuses for circuits where signals must be given when fuses open. Fuses range in sizes from 1/500 amperes up—and there's a companion line of fuse clips, blocks and holders.

559

Dependable protection under all service conditions.

Every BUSS or FUSETRON fuse is tested in a sensitive electronic device that automatically rejects any fuse not correctly calibrated, properly constructed and right in all physical dimensions.

If you have a special protection problem.

The world's largest fuse research laboratory, plus the experience gained by solving all types of electrical protection problems is on call to you at all times. Our engineers, work with yours and can most probably save you time and trouble.

For more information, write for BUSS bulletin SFB.

BUSSMANN MFG. DIVISION,
McGraw-Edison Co.
University at Jefferson, St. Louis 7, Mo.

BUSS fuses are made to protect - not to blow, needlessly.
BUSS makes a complete line of fuses for home, farm, commercial, electronic, electrical, automotive and industrial use.

FUSETRON
TRUSTWORTHY NAMES IN ELECTRICAL PROTECTION
BUSS
McGRAW EDISON

IRE People

(Continued from page 60A)

ured to an accuracy of one part in one million millions (one followed by 12 zeros).

Mr. Havens has been with IBM since 1946 when he joined the Watson Laboratory in New York City as a senior staff member. He is credited with the development of basic circuitry which is essential to computers such as the 701 and the NORC (Naval Ordnance Research Calculator). He was in charge of development and construction of the latter.

In World War II, Mr. Havens led a research group in the Airborne Division of the Radiation Laboratory at M.I.T. For his success as co-inventor and project engineer in charge of developing radar bombing devices, he was awarded the Presidential Certificate of Merit by President Truman in 1948.

Mr. Havens, whose inventions warrent over 30 patents issued or pending, received degrees of B.S.E.E. from the University of Washington, and M.S.E.E. from California Institute of Technology. He is a member of the Men's Faculty Club of Columbia University, of Tau Beta Pi, and Sigma Xi.

❖

M. H. Hayes

H. M. Williams

Link Aviation, Inc., in Palo Alto, California, has announced the appointment of **Monson H. Hayes** (S'48–A'50–M'55–SM'55) as vice-president in charge of research. His former position as technical director of the Research and Development Laboratory will be assumed by **Hugh M. Williams** (M'53–SM'55).

Mr. Hayes is a graduate of the University of Maine and received the M.S. degree from M.I.T. During his period of graduate study he was associated with M.I.T.'s "Project Whirlwind." He joined Link in 1950 and for several years served as head of the company's systems engineering group. When Link established a laboratory in Palo Alto in 1957, he was selected as its technical director.

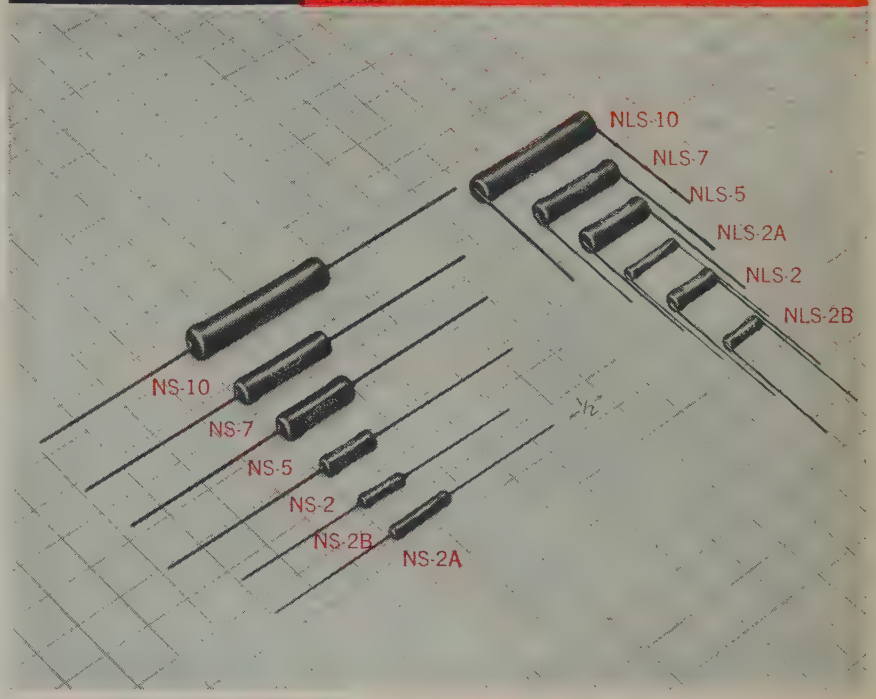
In his new position, Mr. Hayes will be responsible for management of Link engineering operations including the company's laboratories in both Binghamton, N. Y. and Palo Alto, Calif.

Mr. Williams comes to Link from the Martin Company, where he has been manager of the Airborne Electronic Department at the Orlando Division since 1957. Pre-

(Continued on page 64A)

DALOHM Ω

...for Complete Reliability Under Severe Environmental Conditions



TYPE NS, NLS NON-INDUCTIVE POWER RESISTORS

Wire Wound, Precision, Miniature, Ruggedized

Designed specifically for non-inductive requirements coupled with high power and precision tolerance applications. Available with axial leads —NS TYPE; with radial leads—NLS TYPE (for printed circuitry).

Gives reliability under severe environmental conditions.

- Rated at 2, 3, 5, 7 and 10 watts.
- Resistance range from 1 ohm to 37K ohms, depending on type.
- Tolerance: ± 0.05%, ± 0.1%, ± 0.25%, ± 0.5%, ± 1% and ± 3%.

TEMPERATURE COEFFICIENT: Within ± 0.00002/Degree C.

OPERATING TEMPERATURE RANGE: −55° C. to 275° C.

SMALLEST IN SIZE: From 3/32" x 9/16" up to 3/8" x 1-25/32".

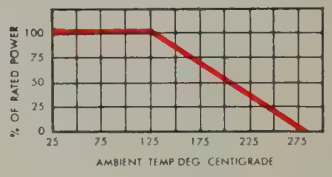
COMPLETE PROTECTION: Impervious to moisture and salt spray.

WELDED CONSTRUCTION: Complete welded construction from terminal to terminal.

SILICONE SEALED: Offers maximum resistance to abrasion, and has high dielectric strength.

Write for Bulletin R-34

DERATING CURVE NS-2A



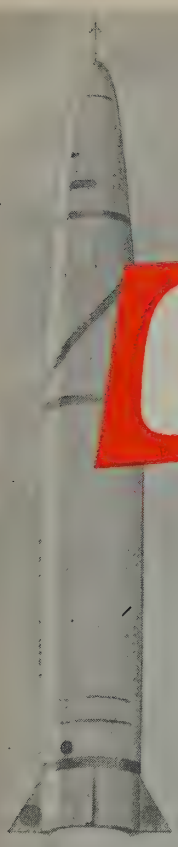
JUST ASK US

The DALOHM line includes precision resistors (wire wound and deposited carbon) and trimmer potentiometers; resistor networks; collet fitting knobs and hysteresis motors designed specifically for advanced electronic circuitry.

If none of the DALOHM standard line meets your need, our engineering department is ready to help solve your problem in the realm of development, engineering, design and production.

Just outline your specific situation.

DALE PRODUCTS INC.
1302 28th AVE.
COLUMBUS, NEBRASKA



Our most potent weapon in the battle of time:

QRC*

In advanced military electronics research, the ability to do the job *isn't good enough.* The job must be done *reliably* and *on time.*

Hallicrafters' QRC program was originated to provide not only the finest of engineering facilities and people, but the flexibility required for immediate, crash effort on critical electronics problems.

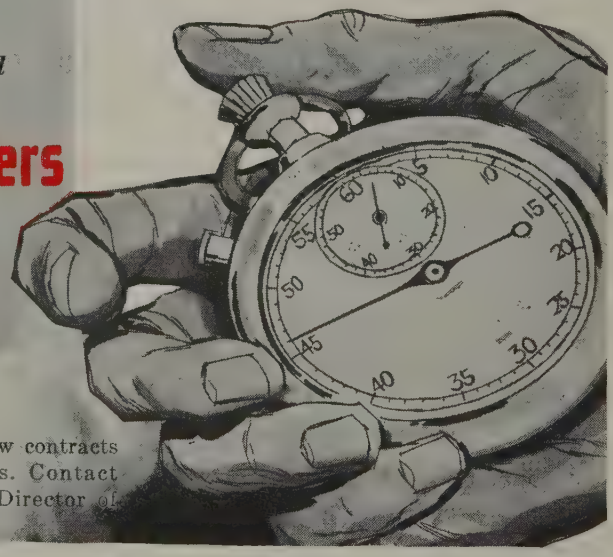
Hallicrafters has provided our military forces for the past six years with a Quick Reaction Capability that has played a major role in helping to win the battle against time.

* Quick Reaction Capability: Refer to Air Force Reg. No. 80-32

The tough jobs get off the ground in a hurry at ....

hallicrafters

Chicago 24, Ill.



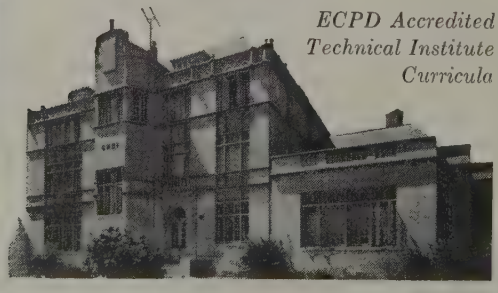
Qualified Engineers: new contracts have created openings. Contact William F. Frankart, Director of Engineering.

CAPITOL RADIO ENGINEERING INSTITUTE

Advanced Home Study and Residence Courses in Practical Electronics, Automation, and Industrial Electronics Engineering Technology

Pioneer in Electronics Engineering Instruction Since 1927

ECPD Accredited Technical Institute Curricula



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3224 16th St., N. W. Washington 10, D. C.

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(Continued from page 63A)

viously, he held responsible positions with Melpar, Inc., the RCA-Victor Division of the Radio Corporation of America, and the South Carolina Public Service Authority.

His new responsibilities will include the direction of research and development projects, including control and guidance systems, instrumentation, components applications, communications, and microwaves.

Mr. Williams received the B.S. degree in electrical engineering from the University of South Carolina. He is a member of the American Rocket Society.

❖

Lowell Technological Institute Research Foundation has announced the appointment of **Kenneth F. Kinnard** (S'52–A'53–M'57) as technical director of their electronics section. In his new capacity he will have charge of all electronic research and development activities of the Foundation.

K. F. KINNARD

Prior to joining the staff of the Research Foundation, Mr. Kinnard spent three years with the Communications Group of Hycon Eastern, Inc., engaged in work on instrumentation problems in the field of high-precision oscillator design. He also worked on the design of integrated telecommunications systems for the United Kingdom of Libya and engaged in several other engineering development activities, including the design of missile telemetering systems, wired television systems, and speech compression and intelligibility studies.

Before joining Hycon Eastern, he was associated with the research department of Melpar, Inc., from 1954 to 1956, where he did research in atmospheric electricity and also made intensive studies of air navigation systems.

From 1952 to 1954, he was on the staff of the M.I.T. Lincoln Laboratory, where he participated in the development of high-frequency, wide-band communications and radar systems. He was responsible for the ground-to-air communications system for the Laboratory, as well as for substantial portions of the design and equipment installations that were used in the detailed studies of one of the first tropospheric-scatter, radio-propagation circuits.

Mr. Kinnard received the B.S. degree in physics and mathematics from Northeastern University where he also did graduate study in electrical engineering.

❖

(Continued on page 70A)

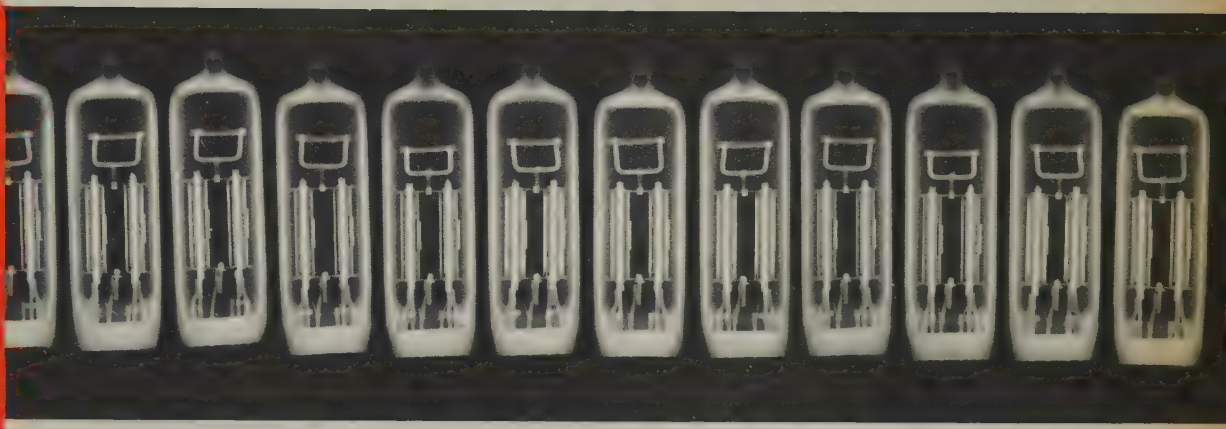
Use your IRE DIRECTORY! It's valuable!

Electron Tube News —from SYLVANIA

SYLVANIA CREATES A

New Profile of Dependability

IN GOLD BRAND TUBES



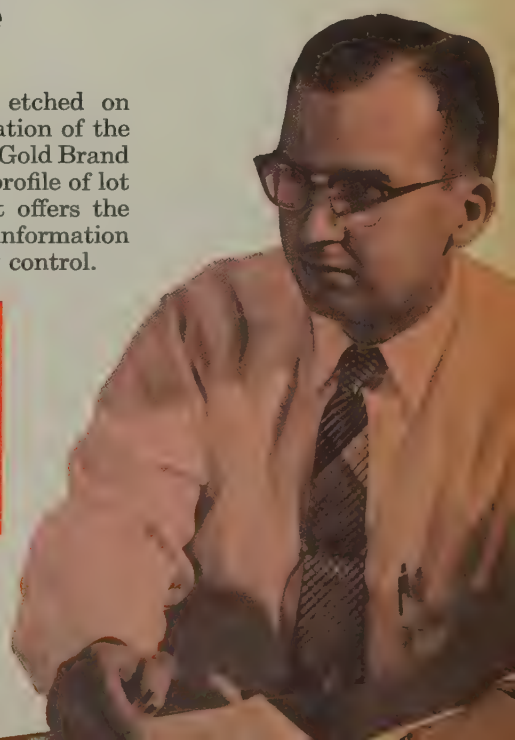
RADIOGRAPH PROFILE shows the superior uniformity of Gold Brand Tubes

Exclusive design, production and identification techniques add extra reliability and efficiency to Gold Brand Tube performance

The perfect uniformity of its physical profile is symbolic of the new level of reliability in Sylvania Gold Brand Tubes. It represents the results of exclusive design and production techniques developed and refined at one of the world's most advanced tube facilities, The Sylvania Gold Brand Plant in Burlington, Iowa.

The unmatched reliability of the Gold Brand "New Concept Bulb" is evident in latest test data. Hourly thermal shock tests (100°C to 0°C) indicate less than 2/10% tip failure during the past two years. This record is due to Sylvania-developed automation equipment, such as the "New Concept" tubulated bulb machines, and to tight quality controls maintained throughout the entire Gold Brand manufacturing process.

The Production Lot Letters etched on its envelope are another indication of the extra dependability of Sylvania Gold Brand Tubes. They are the key to a profile of lot production and test data that offers the user more precise application information and provides for better quality control.



THE EXCLUSIVE LOT LETTERS on each Sylvania Gold Brand Tube identify a complete file of production and test characteristics for individual tube lots

SYLVANIA CREATES A NEW PROFILE O

SYLVANIA'S ORIGINAL folded coil heater design is processed in this ultra-clean room to prevent contamination

ALL TUBE MOUNTS are precision-welded under stereo microscope

New heater design increases tube efficiency

Sylvania has increased the efficiency profile of Gold Brand Tubes by an exclusive heater design, automatic cathode tabbing and by extra control over the environment in which cathode and heater operations are performed.

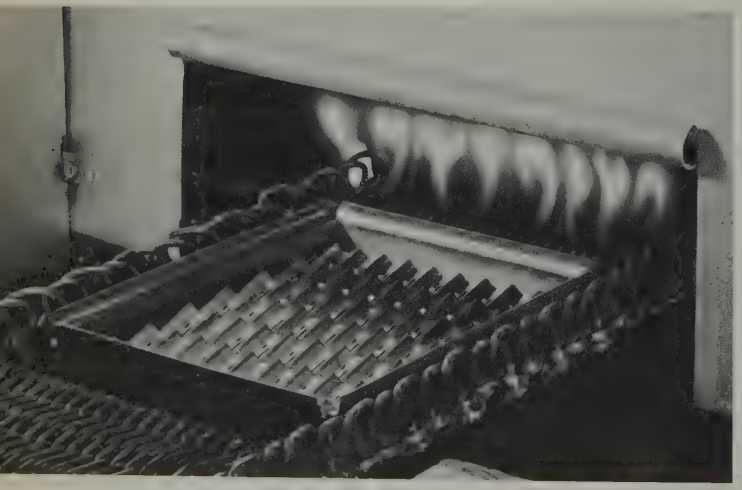
The Sylvania-pioneered folded coil heater used in Gold Brand Tubes permits use of heavier wire for extra ruggedness, permits use of heavier insulation, and allows the cathode to run at higher temperatures for added efficiency at lower heater voltages. The U shaped coil used in double section tubes requires but two welds instead of four, giving extra reliability.

All coating and tabbing operations for heaters and cathodes are performed in a specially air conditioned and filtered room within Sylvania's Gold Brand air-conditioned plant in Burlington, Iowa. Greater cleanliness is achieved to eliminate possible impurity contamination.

Microscopic welding adds ruggedness

All fine welding operations such as heater welds for Gold Brand Tubes are made under stereoscopic microscope to assure weld perfection.

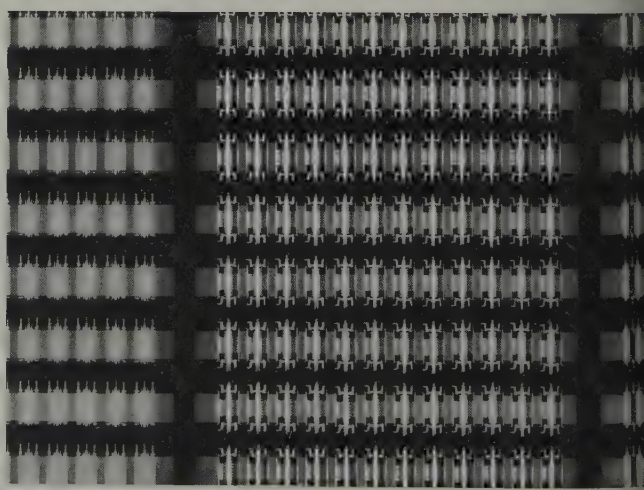
Specially developed weld energy sources such as phase control, slope control and stored energy units are utilized. Weld pressure and current are constantly controlled through Sylvania-patented measuring devices to obtain the strongest and most reliable welds.



EXCLUSIVE FLAME SHIELD firing of grids and parts removes microscopic lint particles

Exclusive flame shield process improves tube performance

All Gold Brand grids and parts undergo Sylvania's exclusive flame shield firing just prior to processing in a high-temperature reducing atmosphere. Contaminations such as lints, oxides and gases are eliminated. The flame shield removes microscopic lint particles.



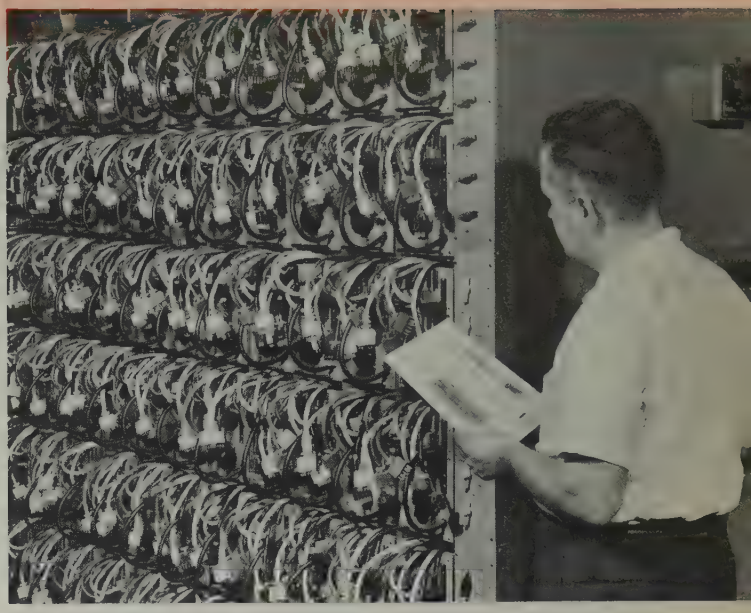
RADIOGRAPH PROFILES of Gold Brand mounts insure against hidden defects

X-ray reveals mount reliability

Even though every mount for Gold Brand Tubes undergoes 100% microscopic inspection, Sylvania carries quality control a step further by using X-ray as a process control on all Gold Brand mounts. X-ray is also used as a 100% inspection tool where appropriate throughout the entire manufacturing process.

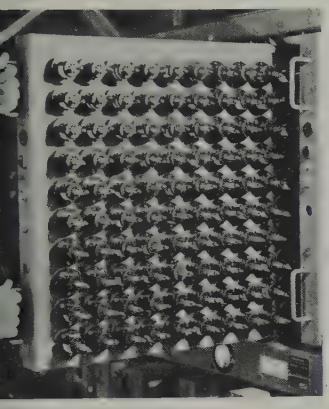
EPENDABILITY IN GOLD BRAND TUBES

VER 1.5 MILLION TUBES a month receive burn-in stabiliza-ion on specially designed stabilization equipment



ALL SYLVANIA GOLD BRAND TUBES receive thermal and electrochemical aging on Sylvania designed equipment

Advanced testing techniques insure top Gold Brand performance



Through continual improvement of its processing and testing methods, Sylvania Gold Brand Tubes are setting new performance records.

All Gold Brand Tubes receive thorough burn-in to insure optimum stability of electrical characteristics both initially and throughout life. Sylvania burn-in facilities are among the industry's largest. Up to 2 million tubes are stabilized each month!

Every Gold Brand Tube also receives highly refined thermal and electrochemical aging on Sylvania designed automatic equipment. Specialized Cyclic processing is used for optimum pulse emission levels and reduced hum levels.

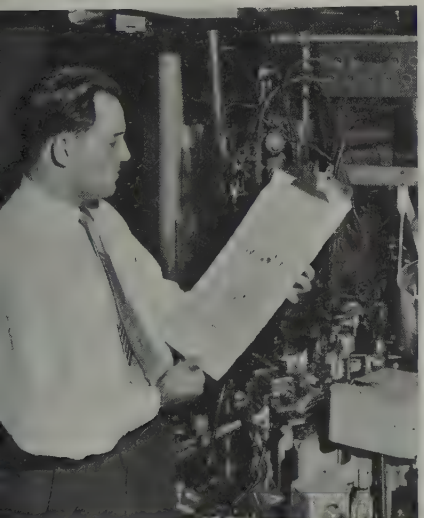
In addition to heater cycle life tests, environmental tests and thermal shock tests, every Gold Brand Tube goes through a final electrical test for pulse emission, AF noise, mutual conductance at rated and reduced EF, static characteristics, shorts, and continuity. Gold Brand Tubes are also subjected to 100% microscopic inspection.

Better vacuums achieved for Gold Brand Tubes

More efficient vacuums have been achieved for Gold Brand Tubes through the use of improved exausting and gettering techniques. Evacuation is performed on automatic equipment with tubes individually evacuated on oil diffusion pumps.

Control charts are maintained over all phases of sealex operation including vacuum measurements on individual heads to improve vacuums. An emission activation control chart is also maintained to reflect control of emission related items.

After sealing, pure barium getters are post flashed to insure maximum gas elimination. Specially designed RF induction heating installations are used so that other tube elements are not affected.



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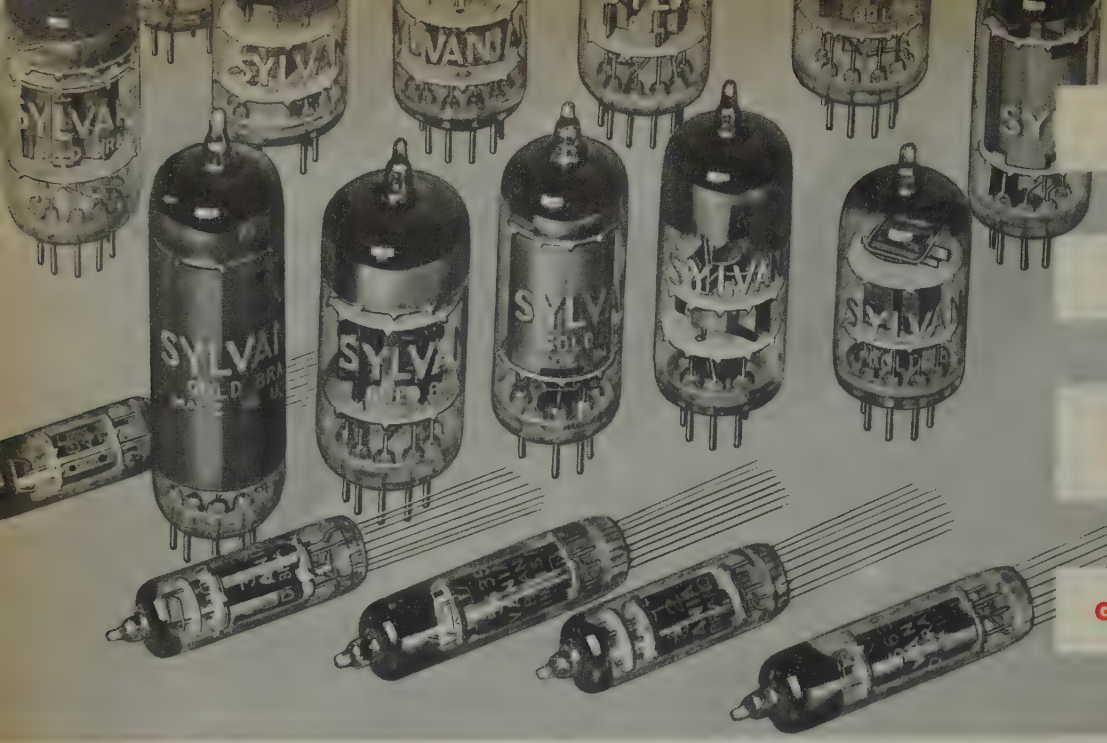

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Professional Group on Nuclear Science

The growth of the radio engineering field over the past decade has been remarkably rapid and shows every indication of continuing in rather spectacular fashion for many decades to come. Much of the progress to date has been in the development of new and improved means of communications. However, the progress of the future promises to be more and more in the application of radio and electronics in areas outside the communications field.

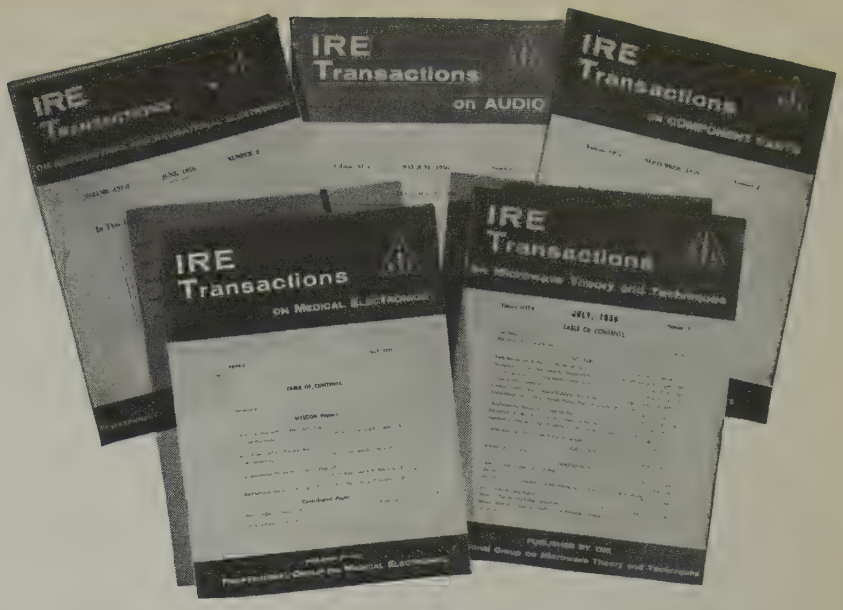
In the Fall of each year the IRE Professional Group on Nuclear Science holds its national annual meeting. The significance of this event goes considerably beyond the meeting itself, for it points up the fact that the future is upon us and that already radio engineering is finding important applications in "non-radio" fields. It is significant also that this field of the future is already being served as an active IRE Professional Group.

The Nuclear Science Group had its beginnings shortly after the war when the IRE formed a Nuclear Science Committee to provide a forum for those engineers and scientists who worked in the new and rapidly developing field of nuclear technology. The Nuclear Science Committee gave rise to the Professional Group on Nuclear Science, which has now grown to 1600 active members, with Chapters in Albuquerque, Boston, Chicago, Connecticut, Dayton, Los Alamos, Oak Ridge, Pittsburgh, and Washington, D.C.

In addition to its own annual meeting, the Group has sponsored sessions at the Annual Conference on Electronic Instrumentation in Medicine and Nucleonics and at the IRE National Convention. More recently, it has expanded its activities by publication of TRANSACTIONS, devoted to reporting important, recent technical developments and news of interest to its members. This young field is already profiting greatly from the many and expanding activities of the Professional Group on Nuclear Science.

W. R. G. Baker

Chairman, Professional Groups Committee



At least one of your interests is now served by one of IRE's 28 Professional Groups

Each group publishes its own specialized papers in its *Transactions*, some annually, and some bi-monthly. The larger groups have organized local Chapters, and they also sponsor technical sessions at IRE Conventions.

Aeronautical and Navigational Electronics (G 11)	Fee $2
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IRE Professional Groups are only open to those who are already members of the IRE. Copies of Professional Group Transactions are available to non-members at three times the cost-price to group members.

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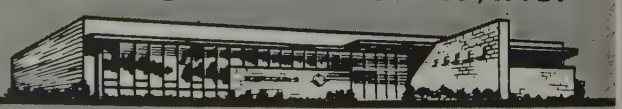

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REgent 6-9330 TWX Sunnyvale, Calif. 116

IRE People

(Continued from page 64A)

The appointment of **Arno Nash** (S'49–A'49–M'55) as vice-president and general manager of the Radio Receptor Selenium Division of General Instrument Corporation has been announced. Mr. Nash, a specialist in the selenium semiconductor field, was formerly Eastern regional manager for International Rectifier Corporation. In his new post he will be in complete charge of operations for the Selenium Division of Radio Receptor Company, wholly-owned General Instrument subsidiary.

A. NASH

He received the B.S. degree in electrical engineering in 1949 from Cornell University and did post-graduate work at Rutgers University. He was employed for two years in the Components Division of the Signal Corps Electronics Laboratories at Fort Monmouth, N. J. before joining International Rectifier Corporation in 1952.

Mr. Nash is a member of the American Institute of Electrical Engineers.

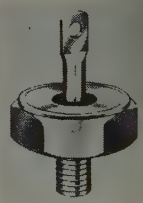
❖

(Continued on page 72A)

New Components from U. S. Semcor

FIRST 25W ZENER DIODE

U. S. Semcor's high power, lightweight zeners include the industry's first 25-watt zener diode. Voltages range from 7 to 100 volts. Extremely low zener impedance and abrupt breakdown are achieved through single silicon diffused junction technique. These hermetically sealed diodes are not position-sensitive and are highly resistant to vibration.



NEW 1N253 THRU 1N256 SERIES

U. S. Semcor's medium power 10-32, 7/16 hex stud mount rectifiers feature maximum temperature range from −65° to +175°C, excellent heat dissipation, low saturation current, and forward conductance of 2 amps at 2 volts. PIVs range from 95 to 570 in a single diffused junction.

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How to keep your cut-off sharp!

Audio filter designers use molybdenum permalloy powder cores when they want razor sharp attenuation that will hold

Audio filter designers, faced with a crowded frequency spectrum, specify molybdenum permalloy powder cores to rigidly define channel cut-offs . . . with sharp, permanent attenuation at channel cross-overs.

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Compare molybdenum permalloy to powdered iron. See the smaller size and the superior stability despite unusual fluctuations in current or temperature. Even unstabilized permalloy powder cores are more stable with temperature swings than cores made of any other material. And . . . stabilized cores are at least four times more inductance-stable than unstabilized cores.

What's more, there's no longer any guesswork! We have published limits within which the designer can depend on core performance. These limits—and full information on our Performance-Guaranteed permalloy powder cores—await your inquiry. *Magnetics, Inc., Dept. P-61, Butler, Pa.*

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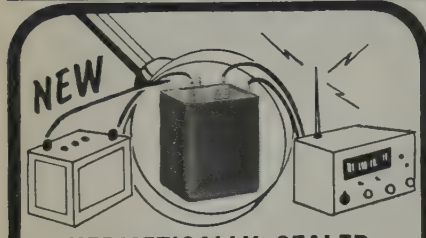

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TRANSISTOR CONVERTERS

- Meets MIL Specifications
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- Highly Compact Package
- No Moving Parts

By combining the best square loop magnetic materials with the latest in transistor development Freed transistor converters solve power supply problems of operating communications equipment from low voltage batteries. AVAILABLE FROM STOCK

DC to DC CONVERTERS

Freed No.	Input VDC	Output VDC	Output IDC	Size
MAC- 6.2.1	6.3	150	.049	2⅝W x 2¼D x 3½H = DC2B
MAC- 6.3.1	6.3	195	.080	3⅞H x 3-9/16 x 3-1/16 = JB
MAC-12.2.1	12.6	300	.043	DC2B
MAC-12.2.2	12.6	180	.072	DC2B
MAC-12.4.1	12.6	390	.100	JB
MAC-12.4.2	12.6	245	.170	JB
MAC-12.4.3	12.6	350	.120	JB
MAC-12.4.4	12.6	225	.218	JB
MAC-26.2.1	26	250	.100	DC2B
MAC-26.2.2	26	600	.043	DC2B
MAC-26.2.3	26	360	.072	DC2B
MAC-26.4.1	26	600	.140	JB
MAC-26.4.2	26	450	.190	JB
MAC-26.4.3	26	450*	.190	JB

*Tap at 225 Volts *Also available for AC Square wave output at slightly higher ratings.*

DC to AC CONVERTERS

Freed No.	Input Voltage	Output VA	Output Voltage and Frequency	Output Regulation	Weight
MAC-16.30.1**	6 volt battery	150 watts max. Fixed Load	115 volts* 60 cycles		7 lbs
MAC-12.20.1**	12 volt battery	170 watts Fixed Load	115 volts* 60 cycles		7 lbs
MAC-12.30.2**	12 volt battery	250 watts max.	115 volts* 60 cycles	10%	16 lbs

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Maximum Direct Current: 1 Ampere

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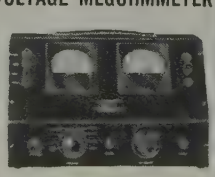
VARIABLE TEST
VOLTAGE MEGOHMMETER



Variable DC test voltage: 50 to 1000 volts
Resistance range: .1 meg ohm to 4,000,000 megohms

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IRE People

(Continued from page 70A)

Robert E. Rutherford (S'55–M'58) has been named manager of the Vacuum Tube Section of the CBS Laboratories' Physics Department, it has been announced.

R. E. RUTHERFORD

Mr. Rutherford, formerly vice-president and chief engineer of the Massachusetts Television Institute of Boston and later director of tube operations of the Research and Development Section of DuMont Laboratories, pioneered in the development of the image dissector, photomultiplier, and image converter tubes. He has made notable contributions in other areas, including electron gun design, nonfocusing deflection plates, color tubes, storage tubes, monoscopes, and cathode-ray tubes with unusually high writing rates.

During the period from 1924–1927 he was a research engineer with Magnavox, where he worked on the single-dial TRF radio set, and for the fo lowing nine years he was a research engineer with Farnsworth Television Laboratories.

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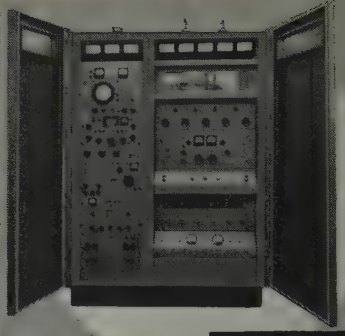
(Continued on page 78A)

AN/FRT-39



BULLETIN 207B

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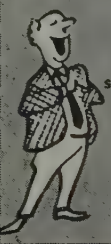

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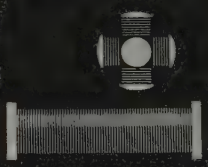

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RW-I to III: Toroidal Winders
RWO: Toroidal (see listing above)
RWP: Precision Potentiometer Winder
ST-I: Stator Winder
AWO: Small Armature Winder
AWO A: Fully Automatic Armature Winder
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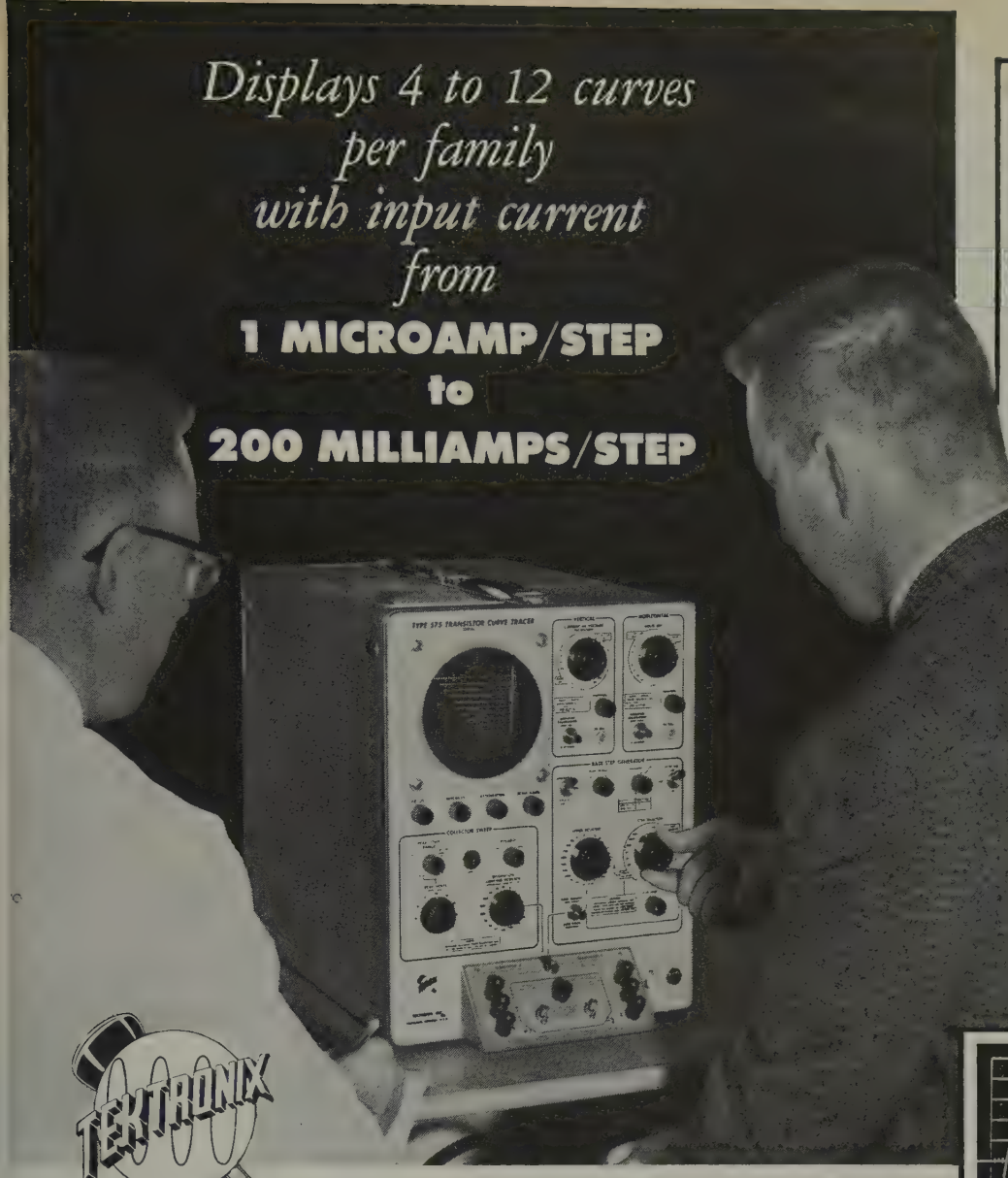
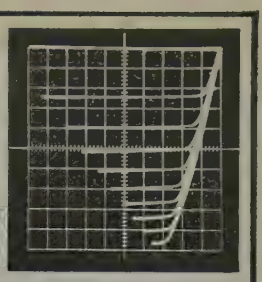
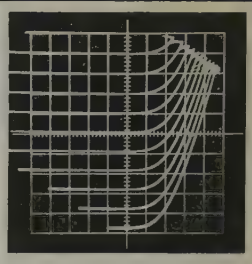




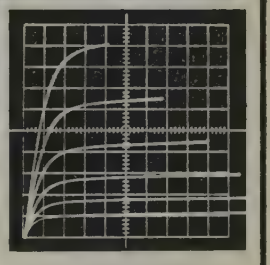
HIGH COLLECTOR CURRENT

PNP transistor, collector current vs collector voltage with constant-current base steps. Collector sweep is 0 to 5 v with a 0.25-ohm load, base current is 50 ma/step. Vertical deflection is 1000 ma/div, horizontal 0.5 v/div.



HIGH INPUT CURRENT

PNP transistor, collector current vs collector voltage with base grounded and constant-current emitter steps. Collector sweep is 0 to 1.5 v, emitter current 200 ma/step. Vertical deflection is 200 ma/div, horizontal 0.1 v/div. Zero voltage is at center scale.



LOW INPUT CURRENT

NPN transistor, collector current vs collector voltage with constant-current base steps. Collector sweep is 0 to 1.5 v, base current 1 microamp/step. Vertical deflection is 10 microamp/div, horizontal 0.1 v/div.

Transistor-Curve Tracer

20-Ampere Collector Displays

(10-ampere average supply current)

2.4-Ampere Base Supply

TYPE 575 CHARACTERISTICS

Positive or Negative Collector Sweep

Collector supply—0 to 20 v, 10 amperes average current.
—0 to 200 v, 1 ampere average current.

Dissipation limiting resistors—0 to 100-kilohms in 17 steps.

Positive or Negative Base Stepping

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17 current-per-step positions, 1 μa/step to 200 ma/step.

5 voltage-per-step positions, 0.01 v/step to 0.2 v/step, with 24 series resistance values from 1 ohm to 22 kilohms.

Calibrated Display

Vertical axis—

Collector current, 16 steps from 0.01 ma/div to 1000 ma/div.

Pushbuttons are provided for multiplying each current step by 2 and dividing by 10, increasing the current range to 0.001 to 2000 ma/div.

Horizontal axis—

Collector volts, 11 steps from 0.01 v/div to 20 v/div.

Both axes—

Base volts, 6 steps from 0.01 v/div to 0.5 v/div.

Base current, 17 steps from 0.001 ma/div to 200 ma/div.

Base source volts, 5 steps from 0.01 v/div to 0.2 v/div.

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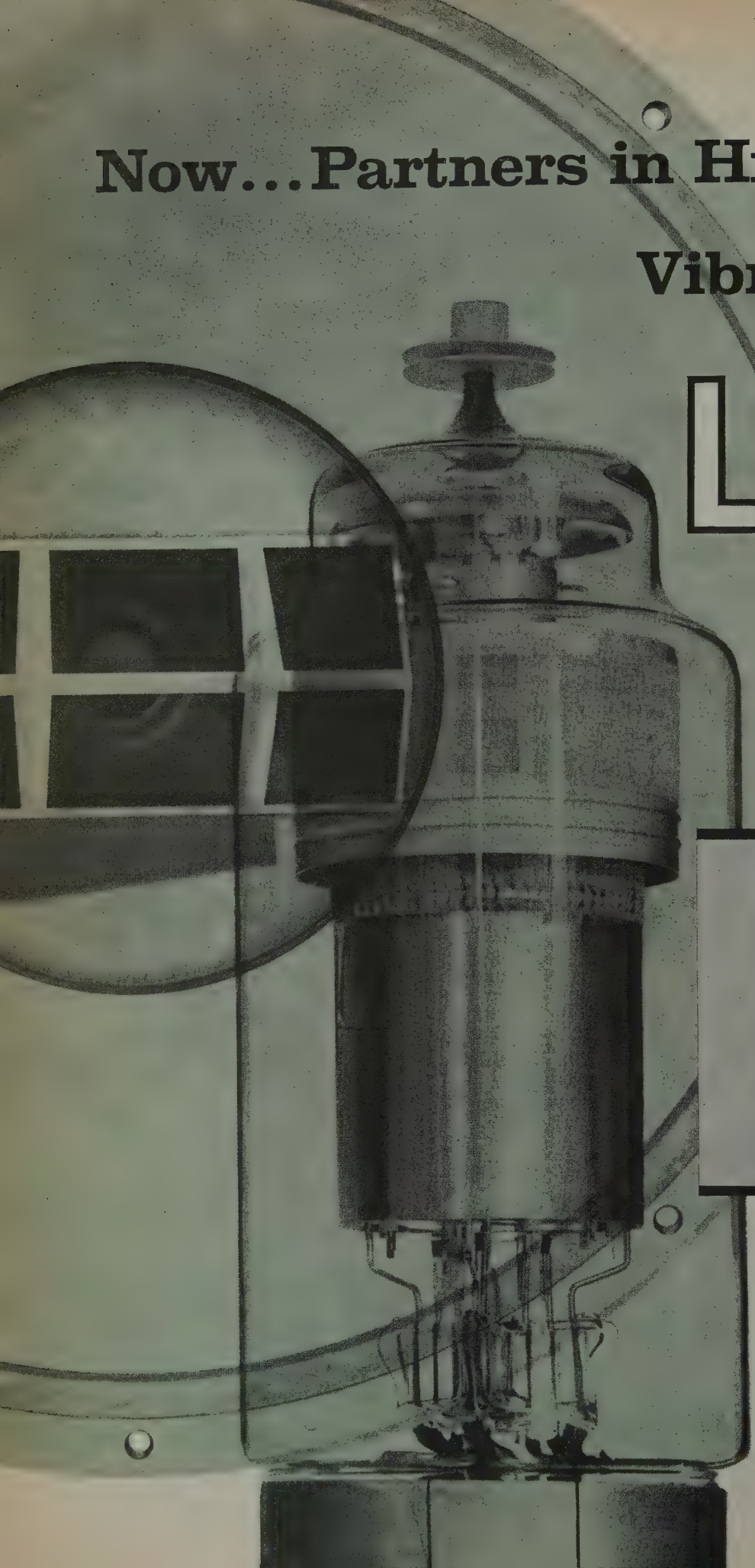

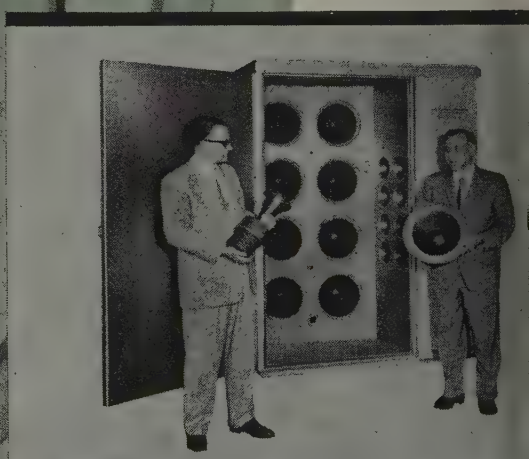

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ALTEC

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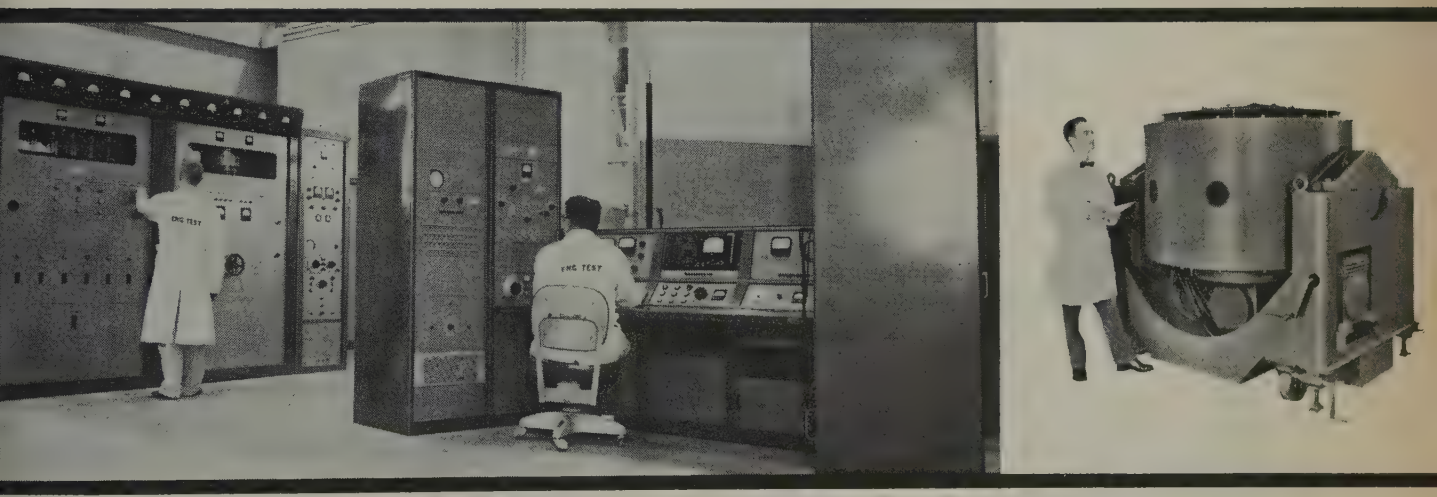
Together, LING/ALTEC provide matched acoustic systems which extend the range and flexibility of vibration testing to meet the most challenging problems of our age.



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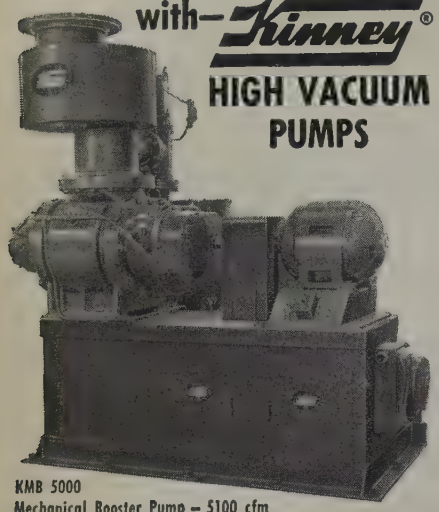
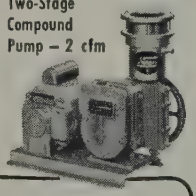


KMB 5000
Mechanical Booster Pump – 5100 cfm

There are many very real advantages in using KINNEY High Vacuum Pumps and High Vacuum Equipment, among which are: the greater dependability of KINNEY Pumps . . . greater economy in operation and maintenance . . . greater pumping speed and the ability to hold low absolute pressures. And, in planning your High Altitude or Environmental Chamber the broad experience of KINNEY engineers can forestall pitfalls now and headaches in the future.

KINNEY pioneered the major advances in High Vacuum technology and today the KINNEY Line of High Vacuum Pumps is the broadest and *most comprehensive in the world!* From small laboratory size Compound Pumps with free air displacement of 2 cfm to two-stage Mechanical Booster Pumps rated at 5100 cfm, there are models to provide the pumping speeds and ultimate pressures you seek.

Get the new KINNEY catalog bulletins and latest information on KINNEY High Vacuum Pumps and Equipment — Write today!



KC 2
Two-Stage
Compound
Pump – 2 cfm

OIL DIFFUSION PUMPS

For Vacuum in the order of 1 x 10-7 mm Hg, the KINNEY Line of High Speed and Fractionating Oil Diffusion Pumps features new design and performance advantages, plus a range of sizes from 1" to 32".

KINNEY MFG. DIVISION
THE NEW YORK AIR BRAKE COMPANY
3631F Washington Street • Boston 30 • Mass.

Please send me bulletins on KINNEY
☐ Mechanical Pumps ☐ Oil Diffusion Pumps

Name_____
Company_____
Address_____
City_____ Zone____ State_____

STODDART COAXIAL TERMINATIONS

operate from −450°F to +440°F

Resistive elements of these units are made of thin platinum films fired at high temperatures on ceramic forms and treated with a protective coating of silicone varnish. These elements do NOT become superconductors at temperatures at least as low as 4.2° Kelvin. Due to the temperature coefficient of the element, however, a unit having a resistance of 60-ohms at room temperature will become a 50-ohm element at this low temperature.

Temperatures as high as +440°F may be induced inside the terminations by an electrical overload of at least 3 times the rated average power dissipation, which is 1 watt. No permanent damage to any part of the termination is produced when subjected to such rigorous treatment.

SPECIFICATIONS:
Frequency range is dc to 3000 mc, 50 or 70-ohm resistance, types "N" or "C" male or female connectors, VSWR is less than 1.2 to 3000 mc and average power dissipation is 1 watt.

Send for literature on complete line of coaxial line terminations, coaxial attenuators and 2, 6 and 10-position turret attenuators.

Immediate delivery

STODDART
AIRCRAFT RADIO CO., INC.
6644 SANTA MONICA BOULEVARD
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5 mc Data Bloc • Data-Pac

Versatile, High-Speed digital building blocks for data handling, data conversion systems . . . special purpose counters . . . process control and automation . . . laboratory research and test equipment.

NMR instrumentation, electromagnets and power supplies, error signal comparator . . . digital components.

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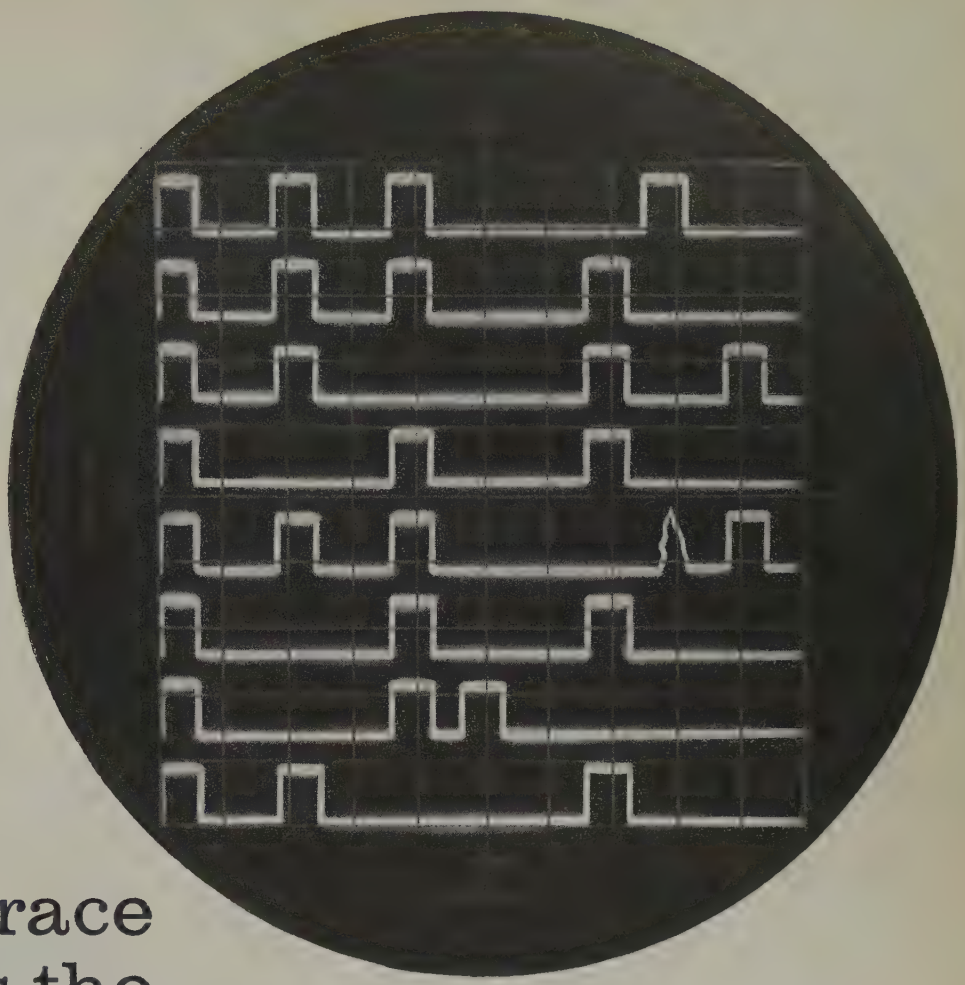
Research and Development Division
5168 WASHINGTON ST., WEST ROXBURY 32, MASS.

Trace Retention with MEMO-SCOPE recorder. Application No. 2



which trace has the transient?

Data reduction systems have long been plagued by false signals from intermittents and transients—particularly those using digital bits and words. With the MEMO-SCOPE® recorder you can locate this false information with comparative ease.

For example, the above display shows 8 traces—one showing a non-recurrent transient pulse. The MEMO-SCOPE recorder freezes this transient information on the face of the tube until intentionally erased. Therefore, transients can be retained for study, regardless of the fact that they are intermittent in nature and last only a few microseconds. For more information concerning this application, write for Data Sheet MSAD-A2.

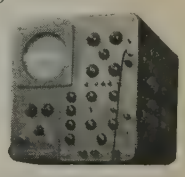
Many unique problems have been solved with the MEMO-SCOPE *recorder through trace retention. Refer your problems to us by writing: Hughes* MEMO-SCOPE *recorder, Hughes Products, International Airport Station, Los Angeles 45, California.*

A new MEMO-SCOPE recorder accessory . . . the **Multitracer** . . . makes it possible for you to automatically program up to 20 different traces on the tube face.

In addition to data reduction trouble shooting, the MEMO-SCOPE recorder makes it possible for you to save time and money in problems associated with:

- *Ultrasonic flaw testing*
- *Drift measurements*
- *Ballistics, explosives research*
- *Switch, relay contact studies*
- *Welding*
- *Transducer testing*
- XY *plotters*
- *Medical diagnosis problems*
- *Physical testing*
- *plus many more*

SPECIFICATIONS:
Sweep Speed for Storage: 10 microseconds per division to 10 seconds per division (0.33″).
Frequency Response: DC to 250 KC down 3 db.
Sensitivity: 10 millivolts to 50 volts per division or with optional high sensitivity preamplifier 1 millivolt to 50 volts per division.



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HUGHES PRODUCTS

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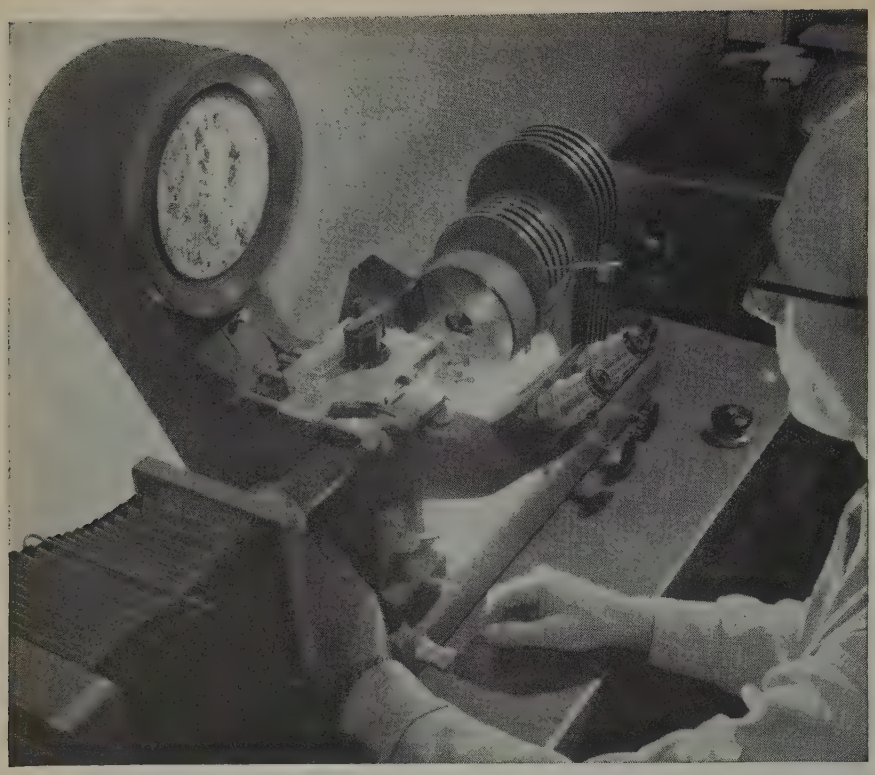

Precise laboratory control insures dependability of KOVAR alloy for glass-to-metal seals

The consistently dependable, vacuum-tight, glass-to-metal bond made possible by KOVAR® alloy is the result of strict quality control through every phase of manufacture. Skilled technicians, using the resources of one of the world's most advanced laboratories, make constant checks to insure that rigid specifications are met.

For example, close control of microstructure, including grain size, is maintained by checking each heat of KOVAR alloy with metallograph shown above.

KOVAR — an iron-nickel-cobalt alloy developed by Westinghouse — matches almost perfectly the thermal expansion curves of several hard glasses and ceramics. It bonds readily with these materials to form a rugged, vacuum and pressure-tight seal that will withstand severe conditions of temperature, vibration and handling. It can be easily welded, brazed, soldered or plated with other metals.

Carborundum offers a large variety of formed parts and assemblies, as well as sheet, strip, rod and tube for immediate shipment. Contact the Carborundum Company, Refractories Division, Dept. PI69, Latrobe Plant, Latrobe, Pa.

FIND OUT ABOUT KOVAR — WHERE IT IS USED AND WHY

This new book gives data on composition, fabricating techniques and applications of KOVAR alloy. Send for your free copy today.

CARBORUNDUM

Registered Trade Mark

IRE People

(Continued from page 72A)

The appointment of **Edmond R. Pelta** (S'53–A'55) as vice-president of Eisler Associates, a data processing systems consulting firm, has been announced by Mr. George Eisler, president. Mr. Pelta, formerly head of the Computer Engineering Group at the System Development Corporation, will take charge of the firm's activities in the instrumentation, electro-optical, photographic, and sensory device fields. He has had extensive experience and is responsible for many novel innovations in these areas.

❖

Albert Preisman (M'38–SM'43) has announced his resignation as vice-president in charge of engineering from Capitol Radio Engineering Institute, which he joined in 1943.

Mr. Preisman has gained a wide reputation in the technical institute field, particularly in the preparation of home study electronic engineering texts.

He now intends to expand his consulting electronic engineering practice, especially in the fields of patent litigation and the preparing and writing of engineering reports.

❖

(Continued on page 84A)

Kepco

VRPS*

the most complete line of POWER SUPPLIES

TRANSISTORIZED MAGNETIC TUBELESS VACUUM TUBE TYPE

*VOLTAGE REGULATED POWER SUPPLIES

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INC.

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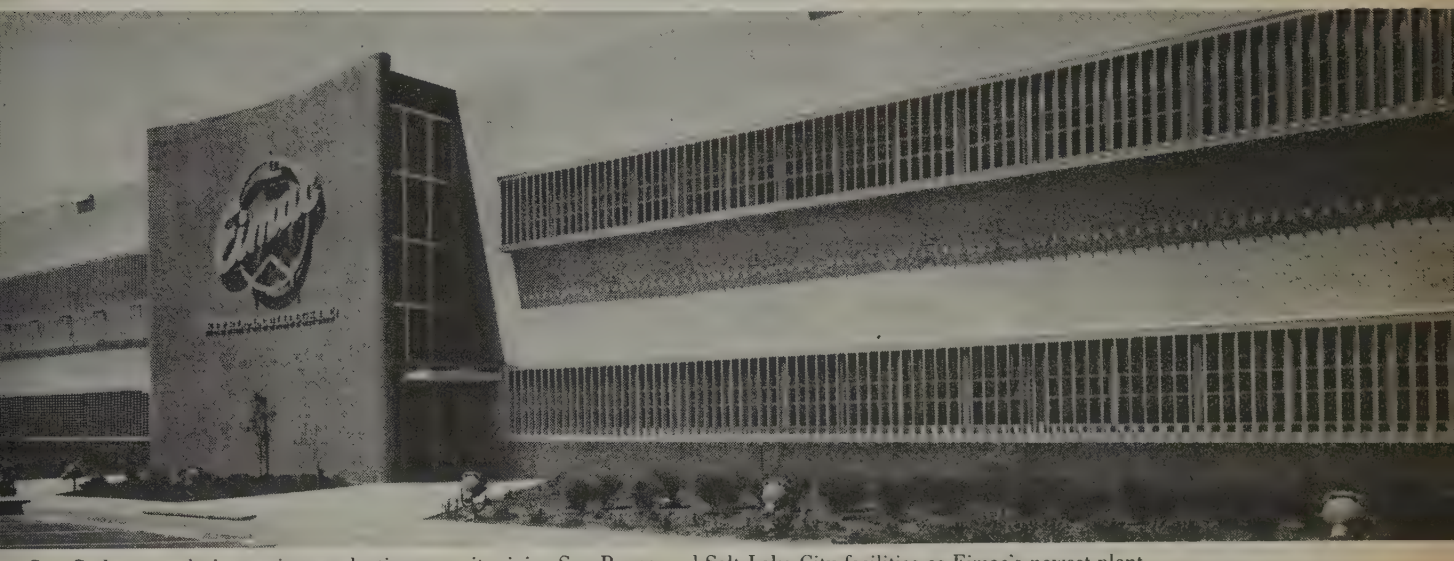
EIMAC TUBES
NOW IN PRODUCTION
IN AMERICA'S NEWEST, MOST MODERN TUBE PLANT

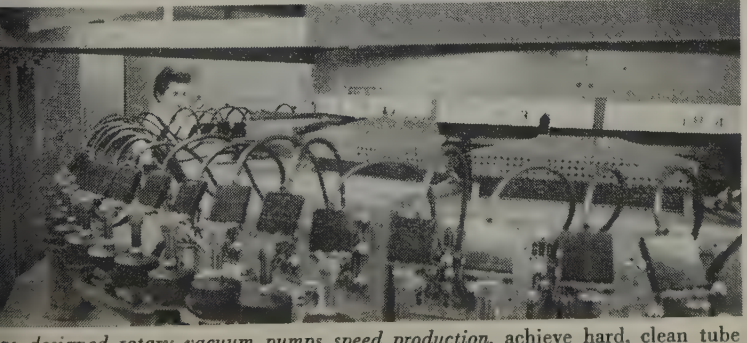
In San Carlos, California, Eimac's third and largest plant is nearing full production to meet the great demand for many popular Eimac electron tube families. Never before have so many advanced techniques and processes been applied to vacuum tube manufacture. Eimac's leadership in new processing methods has brought a new era of quality to electron tubes.

Ready for shipment, these Eimac ceramic tetrodes are just one of more than a hundred different tube types manufactured by Eitel-McCullough, Inc., including negative grid tubes, power amplifier klystrons, reflex klystrons and traveling wave tubes.

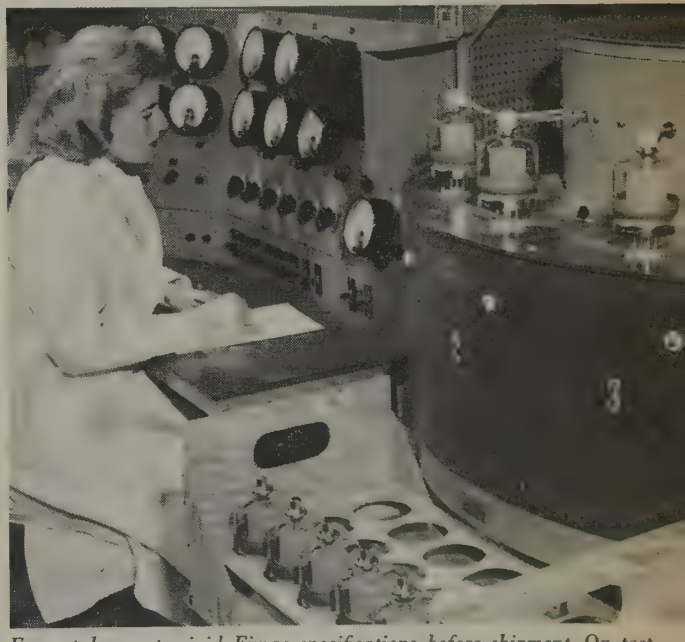


ac, San Carlos, greatly increasing production capacity, joins San Bruno and Salt Lake City facilities as Eimac's newest plant.

l tube assembly in near-sterile "clean rooms" assures exceptional tube reliability. se rooms are pressurized with filtered, conditioned air to prevent the tiniest dust icles from entering. Even shoes are automatically vacuum cleaned as personnel r the room through double-door air locks.



ac designed rotary vacuum pumps speed production, achieve hard, clean tube uums. Pumping Eimac tubes at high voltages and ambient temperatures assures



Every tube meets rigid Eimac specifications before shipment. On test consoles like this, dozens of electrical characteristics are patiently tested and recorded for each Eimac tube produced. Environmental testing equipment is also available for testing for severe applications.

Eimac

EITEL-McCULLOUGH, INC.

SAN CARLOS, CALIFORNIA

MINIATURE TRANSFORMERS FOR *Transistor* AND PRINTED CIRCUIT APPLICATIONS

Custom transformers for printed circuits are now available from ADC in five standard case sizes with terminals and inserts on 0.1" grid multiples. Audio, power, and ultrasonic transformers and inductors with maximum electrical performance for each size are being custom designed for transistor and vacuum tube circuitry. Raised mountings prevent moisture from being trapped. Available in Mumetal cases. They meet MIL-T-27-A Grade 5 Class R or S Life X, and can be designed to meet 500 and 2,000 cps vibration.

TYPICAL RATINGS

AUDIO

Fig.	Description	Primary	Secondary	Maximum Level	Response (CPS)
1	Output	P P collectors 100 ohms CT	600/150 ohms	+33 dbm (2w)	±2db 250-10,000 cps
2	Output	5000 ohms 5ma DC	50/250/600 ohms	+10 dbm (10mw)	±1db 100-10,000 cps
3	Output	P P collectors 1000 ohms CT	4/8/16 ohms	+25 dbm (300mw)	±1db 250-10,000 cps
3	Interstage	Collector, 5000 ohms 1ma DC	P P bases 3000 ohms CT	+5 dbm	±1db 250-5,000 cps
4	Input	50/250/600 ohms	50,000 ohms	+2 dbm	±1db 250-10,000 cps
5	Output	P P collectors 500 ohms CT	4/8/16 ohms	+20 dbm (100mw)	±1db 250-10,000 cps
5	Interstage	Collector 7500 ohms 1ma DC	P P bases 5000 ohms CT	0 dbm	±1db 250-10,000 cps

INDUCTORS

Fig.	Description	Rating			
3	Audio	200 hys	1v	1000 cps	0 DC
5	Power	500 mhys	1v	400 cps	10ma DC

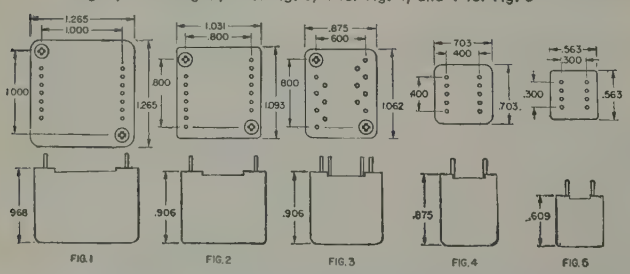
WAVE FILTERS

Fig.	Description		Rating	
3	Low pass	600 ohms input 600 ohms output	+10dbm	f cutoff 50kc Attenuation 18db per octave
3	High pass	10,000 ohms input 10,000 ohms output	+10dbm	f cutoff 2kc Attenuation 18 db per octave

POWER

Fig.	Description	Primary	Secondary	VA	Regulation
4	Filament	115v 380-420 cps	6.3v .6a	4.0	10%
5	Dual filament	26v 380-420 cps	{1} 6v 5ma {2} 6v 5ma	.2	2%

Note: Other combinations are available with 400 cps max. volt ampere ratings up to 15 for Fig. 1, 10 for Fig. 2, 6 for Fig. 3, 4 for Fig. 4, and 1 for Fig. 5



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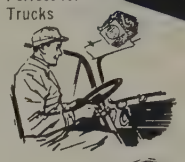
Perfect for Trucks



for:
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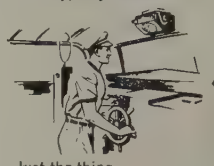
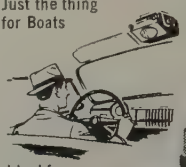
- BOATS
- STATION WAGONS
- SMALL IMPORT CARS
- COMPACT U.S. CARS



Just the thing for Boats



Ideal for Small Cars

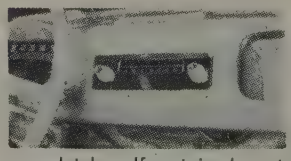
(Patent Applied For)

Illustrating: Model TR 1279—12 Volt with Tone Control

ATR **TRUCK Karadio**

most versatile truck-auto-boat radio ever designed!

The ATR Karadio is a new compact, self-contained airplane-style radio for trucks, boats, station wagons, small import cars, and compact American cars. This handy unit is perfect for trucks because it is easy and inexpensive to install in the cab roof—and its 6-tube radio with powerful 8-tube performance provides remarkable freedom from engine, static, and road noises. The ATR Karadio's single-unit construction (complete with speaker and optional antenna) is also ideal for boats where it can be roof-mounted. For small import and compact American cars, this economical unit can be easily installed in-dash or under-dash, as desired. Available for 6 or 12 volt battery systems!



The ATR KARADIO is ideal for small import cars or compact American cars! Unit is completely self-contained—extremely compact! Can be mounted in-dash or under-dash—wherever space permits!

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Quality Products Since 1931
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NEW!

SMALL!

DELCO POWER TRANSISTOR

Designed for use where space and weight are restricting factors

MAXIMUM RATINGS	2N1172
Collector Diode Voltage	40 volts
Emitter Diode Voltage	20 volts
Collector Current	1.5 Amperes
Junction Temperature	95°C
TYPICAL CHARACTERISTICS (25°C)	
Typ. Collector Diode Current I_{co} V_{cb}=40 volts	50μ
Current Gain (V_{ec}= −2 volts, I_c=100 Ma)	70
Current Gain (V_{ec}= −2 volts, I_c=½A)	30
Saturation Resistance	0.3 ohms
Cutoff Frequency (Common Emitter)	17 kc
Thermal Resistance	12° C/Watt

The 2N1172 is a medium power transistor offering dependable operation in a new range of applications where space and weight have been a problem.

It's a mighty mite with more punch in a smaller package. The 2N1172, excellent for output use or as a driver for a very high power transistor, has already proved especially effective in DC amplifiers, voltage regulators, and as a driver for a high power stage in servo or other amplifiers.

This PNP germanium transistor is housed in a modified version of the JEDEC 30 package with a diamond shaped base for improved thermal conduction. It dissipates up to 2 watts at a mounting base temperature of 70 degrees centigrade. Available now in volume production—write today for complete engineering data.

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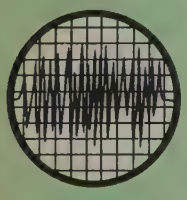

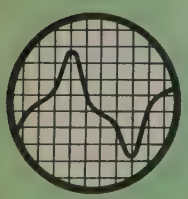

REPRESENTING:

A distinctly new departure in VTVM design.

FEATURING:

A built-in calibrator; — easily read 5-inch log meter; — immunity to severe overload; — useful auxiliary functions.

BRIEF SPECIFICATIONS:

VOLTAGE RANGE: .....100 microvolts to 320 volts
DECIBEL RANGE: ..... — 80 dbv to +50 dbv
FREQUENCY RANGE: .....5 to 500,000 cycles per second
ACCURACY: .....3% from 15 cps to 150KC; 5% elsewhere
Figures apply to *all* meter readings
MAXIMUM CREST FACTORS: 5 at full scale; 15 at bottom scale
CALIBRATOR STABILITY: .0.5% for line variation 105-125 volts
INPUT IMFEDANCE: ....10 MΩ and 25 μμf, below 10 millivolts
10 MΩ and 8 μμf, above 10 millivolts
POWER SUPPLY: .....105-125 volts; 50-420 cps, 75 watt
Provision for 210-250 volt operation
DIMENSIONS: (*Portable Model*) .....14⅜" wide, 10⅛" high, 12⅜" deep—Relay Rack Model is available
WEIGHT: .....21 lbs., approximately

PRICE: $425

Write for the New Ballantine Catalog describing this and other instruments in greater details.

BALLANTINE LABORATORIES, INC.

Boonton, New Jersey

STROMBERG-CARLSON TELEPHONE HANDSETS

. . . for your voice communication needs.

These "push-to-talk" handsets are of the most modern design available.

If your applications are in • **mobile radio** • **intercom systems** • **carrier and microwave** • **aircraft and railroad** — specify Stromberg-Carlson handsets.

No. 26: short, lightweight, sturdy. Comes with capsule-type receiver and transmitter.

No. 28: "push-to-talk" handset. Rocker-bar switch; various spring combinations.

Both models available with standard or high-gain transmitters and receivers. Superior to any other handset on the market.

Modern handset cradle for mobile or panel use

Holds handset firmly; is strong and resilient; fits any Stromberg-Carlson handset. Switch combinations with two or four Form C contacts. Space for your company name is provided. Send for Handset Bulletin T-5005 and Cradle Bulletin T-5013. Write:

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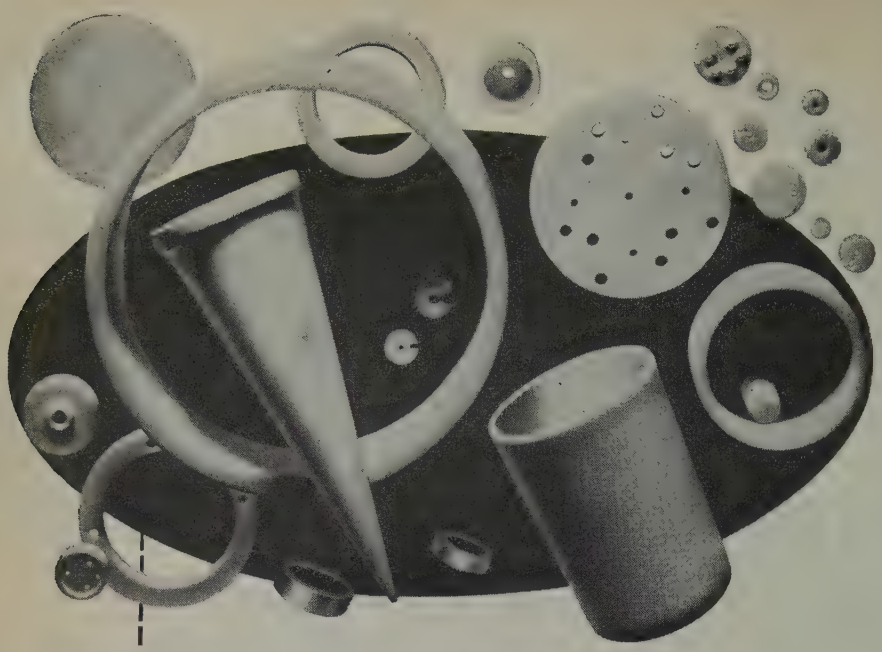

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Material alone does not assure a reliable alumina part . . . the exceptional performance characteristics associated with alumina are directly related to manufacturing knowledge and techniques. Since 1948, Wesgo has perfected the precise controls over composition and manufacturing techniques that alone impart a uniform quality to alumina parts. Quality can only be superficially specified . . . knowledge of alumina ceramics plus quality consciousness are the important extras offered by Wesgo. Alumina is a premium ceramic material . . . but with many cost saving advantages. Be assured of these advantages . . . use Wesgo AL-300 ceramics in shapes to your specifications.

PURE WHITE AND TRANSLUCENT. 97.6% Al_2O_3. Visibly free from impurities. Vacuum tight.

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UNIFORM IN COMPOSITION AND PROPERTIES from lot to lot.

HIGH DIELECTRIC STRENGTH AND RESISTIVITY.

VERY LOW LOSS FACTOR.

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WESTERN GOLD AND PLATINUM COMPANY

Manufacturers of Wesgo Brazing Alloys

BELMONT, CALIFORNIA

IRE People

(Continued from page 78A)

Harold S. Renne (A'41–M'45–SM'48) has been appointed information manager at the Bell Telephone Laboratories, New York, N. Y. He was formerly technical information supervisor.

H. S. RENNE

Mr. Renne joined Bell Labs in 1956 after 12 years with Ziff-Davis Publishing Company, where he was technical editor for the electronics group. Prior to 1944 he had served for three years as an instructor at Illinois Institute of Technology.

He is a past chairman of the New York Section of the IRE.

❖

Robert L. Marshall (M'58) has announced the formation of a new sales engineering organization, DynaSales Company, in Los Angeles, Calif., which will represent several major manufacturers of instrumentation and control systems and

(Continued on page 88A)

NEW... from NEW YORK UNIVERSITY PRESS

PROCEEDINGS OF THE FOURTH NATIONAL CONFERENCE ON TUBE TECHNIQUES

EDITED BY DAVID SLATER AND THE EDITORIAL COMMITTEE: WORKING GROUP ON TUBE TECHNIQUES OF THE ADVISORY GROUP ON ELECTRON TUBES

These 46 papers dealing with problems over the entire range of modern electron tube techniques were presented at the Fourth National Conference in September 1958. They contain discussions of gettering; vacuum methods; sealing for ceramics, metals and glass; structures; microwave tube techniques; cathode and cathode materials; cathode interface; and emission phenomena—and include the following papers by leading men in the field: "Properties of Getters in Electronic Tubes," by J. S. Wagener; "Microwave Vacuum–Tube Techniques in Europe," by H. Huber; "Dispenser Cathodes" by V. L. Stout; "Thermionic Emitters" by L. S. Nergaard; and "Dynamic Equilibrium Processes in Oxide-Coated Cathodes" by W. G. Shepherd.

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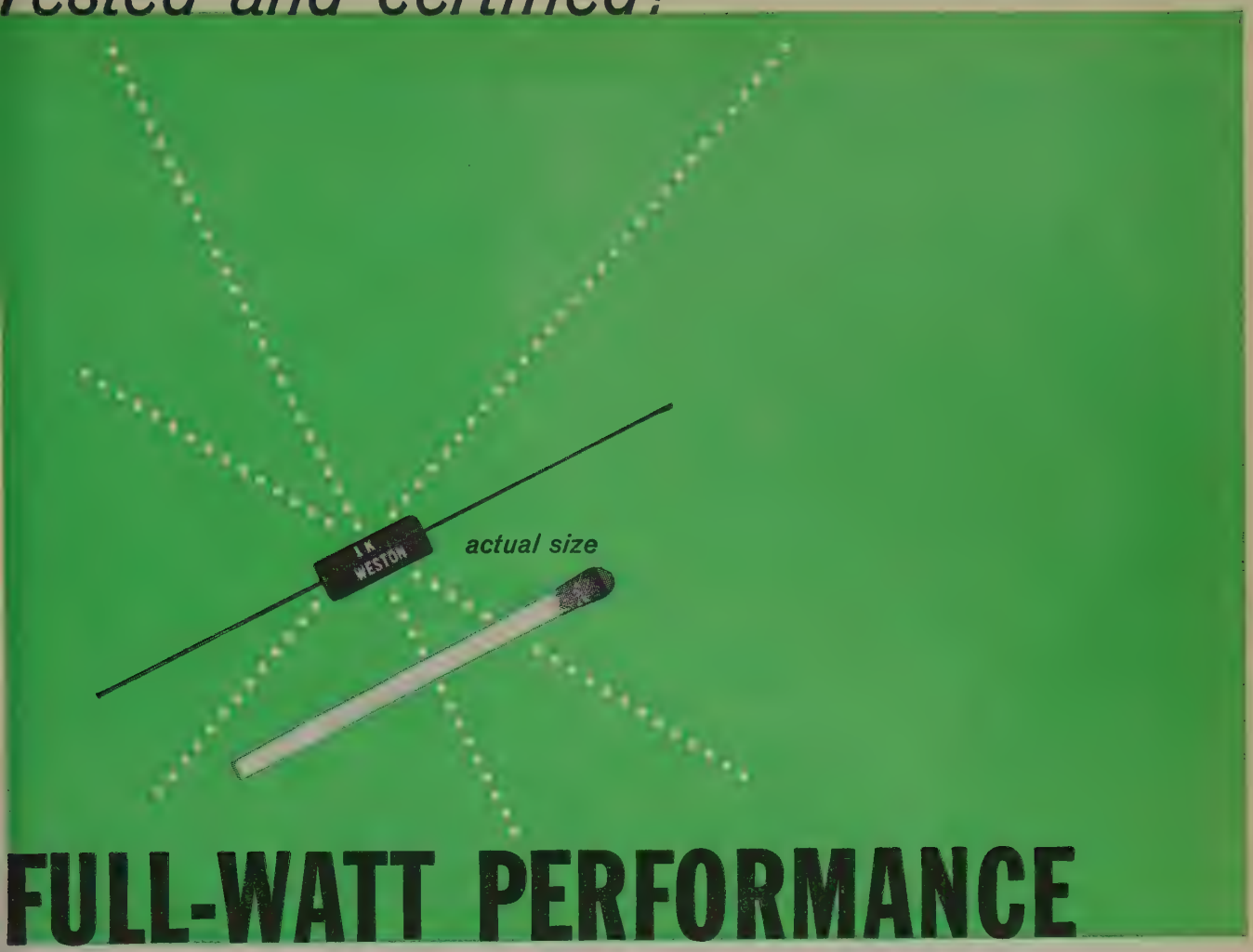


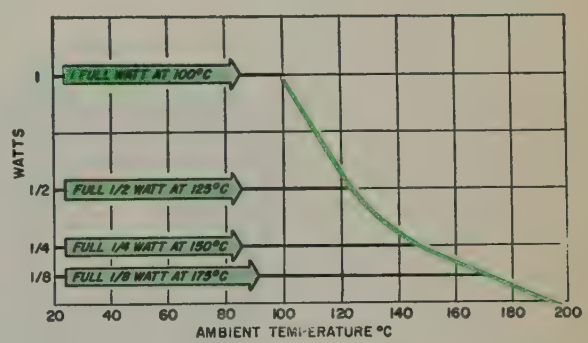
FULL-WATT PERFORMANCE

at 100C in the new, miniaturized 1/4-watt Metal-Film Resistor

Does this performance chart suggest anything to you? Hundreds of electronic, missile, and aircraft design engineers have already taken advantage of this latest Vamistor's extraordinary operating characteristics. Model 9855-4 precision metal-film resistor—another Weston exclusive—may be just the answer to *your* stability, temperature or miniaturization problem.

For example, this resistor, available in values from 50 ohms through 1.5 megohms, has (1) maximum continuous working voltage of 350v . . . (2) temperature coefficient of 25 or 50 ppm . . . (3) tolerances of 1%, .5%, .25%, .1%.

For full information . . . or for the address of your nearest distributor, contact your local Weston representative. Or write direct to Weston Instruments, Division of Daystrom, Inc., Newark 12, N. J.
In Canada: Daystrom Ltd., 840 Caledonia Rd., Toronto 19, Ont.
Export; Daystrom Int'l., 100 Empire St., Newark 12, N. J.



WESTON

A DAYSTROM UNIT

Metal-film Resistors

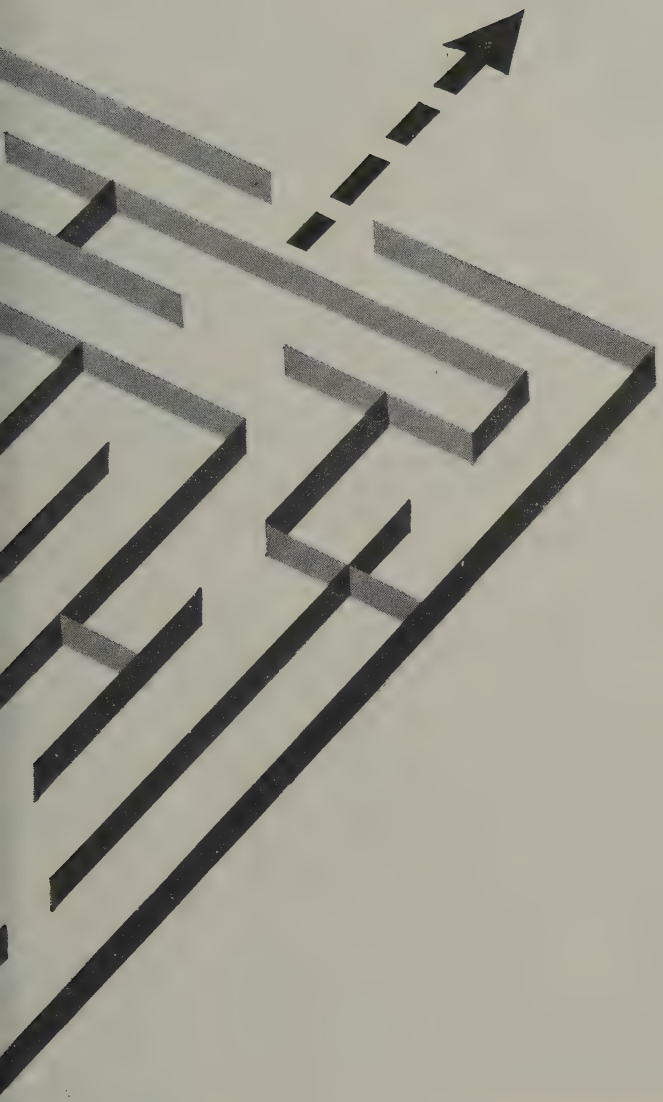
WORLD LEADER IN MEASUREMENT AND CONTROL

Automation cut its teeth on the

...how ITT's early work in telephony advance

elephone

he art of automation



The dial telephone exchange was one of the first examples! Today, automatic switching and new electronic techniques for automation are altering the operations of virtually every business and industry.

It was natural that ITT System companies, pioneers in the first, should be leaders in the second.

Customers have ranged from mail-order houses, railroads, libraries and oil companies to the air forces of several NATO governments.

There have been dramatic results.

One example is the automatic check-processing system developed by ITT System companies for one of the nation's largest banks. It codes, sorts and verifies checks. It performs all normal bookkeeping and accounting operations for demand deposits.

Another is the automation system for a large steel mill which records the program of requirements for every job, then feeds back information to production control centers as each phase is completed.

Still another: the first automatic U. S. post office, now under construction in Providence, Rhode Island.

Hundreds of others could be cited. Each required a complete understanding of automation from the design of a simple switch to the functioning of a fully-integrated electronic complex.

The ITT System has many specialists in this field. Among them: Intelex Systems Incorporated in retained-document automation; Kellogg Switchboard and Supply Company in automatic switching; Airmatic Systems Corporation in automatic-switch pneumatic tube and document-conveyor systems; ITT Federal Division in automatic test equipment, both military and industrial. ITT's European subsidiaries add to this experience.

To learn more about ITT's abilities in the area of automation, write for further information.

. . . the largest American-owned world-wide electronic and telecommunication enterprise, with 101 research and manufacturing units, 14 operating companies and 130,000 employees.

INTERNATIONAL TELEPHONE AND TELEGRAPH CORPORATION 67 Broad Street, New York 4, N.Y.

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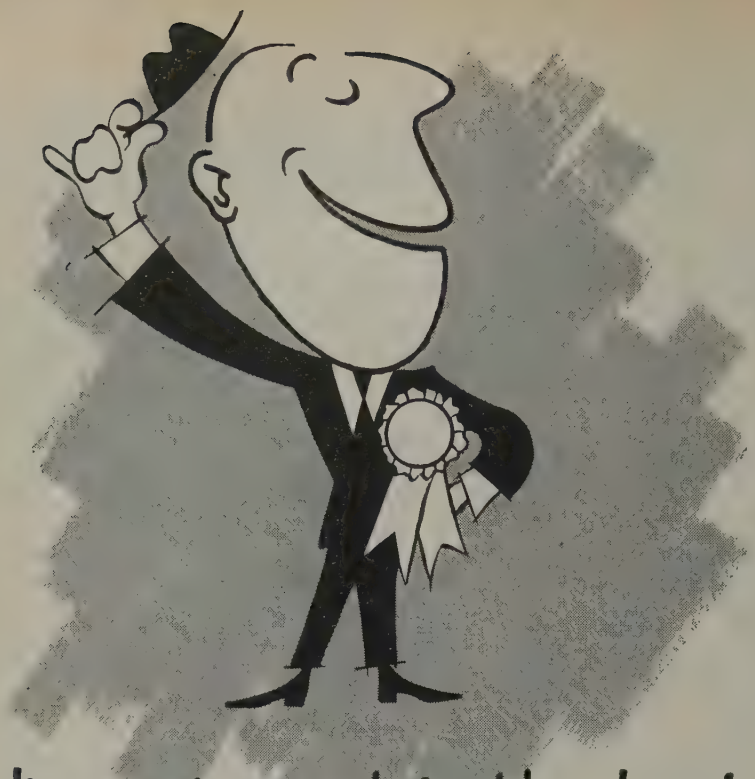
AIRMATIC SYSTEMS CORPORATION • KELLOGG SWITCHBOARD AND SUPPLY COMPANY • ROYAL ELECTRIC CORPORATION • AMERICAN CABLE & RADIO CORPORATION • FEDERAL ELECTRIC CORPORATION • ITT COMMUNICATION SYSTEMS, INC. • INTERNATIONAL ELECTRIC CORPORATION • INTERNATIONAL STANDARD ELECTRIC CORPORATION • LABORATORIES AND MANUFACTURING PLANTS IN 20 FREE-WORLD COUNTRIES



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Hickory Brand Community TV Antenna System Cables provide

- **MINIMUM PICKUP OF EXTERNAL INTERFERENCE**
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Use Hickory Brand Community TV Antenna System Cables, specially designed to meet the requirements of community TV systems with maximum effectiveness.

An overall vinyl jacket minimizes cross cable interference and reduces radiation . . . electrical and physical characteristics are unexcelled.

All Hickory Brand Electronic Wires and Cables are quality-engineered and precision-manufactured to meet the most exacting requirements.

Write for complete information on the full line of

HICKORY BRAND Electronic Wires and Cables

Manufactured by
SUPERIOR CABLE CORPORATION, Hickory, North Carolina

3606

(Continued from page 84A)

related components in the Southern California area.

Mr. Marshall has been active in the area as a sales engineer since 1948. During that time he was employed by Westinghouse Electric Corp., Weston Instruments, a Division of Daystrom, Inc., and Consolidated Electrodynamics Corp.

He is a mechanical engineering graduate of the University of Texas and has completed additional courses in electrical engineering and business administration at the University of Pittsburgh and the University of California at Los Angeles.

Active in numerous industrial and trade organizations in the Southern California area, he is also a member of the ASME, and the ISA.

❖

Robert R. Warriner (S'39-A'41–SM'57) has been named military applications specialist for the Sprague Electric Company. He comes to Sprague from the Aerovox Corporation, where he has been chief applications engineer for the past ten years.

R. R. WARRINER

Well known in the electronics components industry, Mr. Warriner was previously chief applications engineer for the Solar Manufacturing Corporation. During World War II he was in charge of component approvals at the former Aircraft Radio Laboratory of the U. S. Army Signal Corps at Wright Field, Dayton, Ohio. Previously he had been associated with the Belmont Radio Corporation of Chicago for many years as a components parts engineer.

He is a graduate of the South Dakota State School of Mines and Technology and is a registered professional engineer.

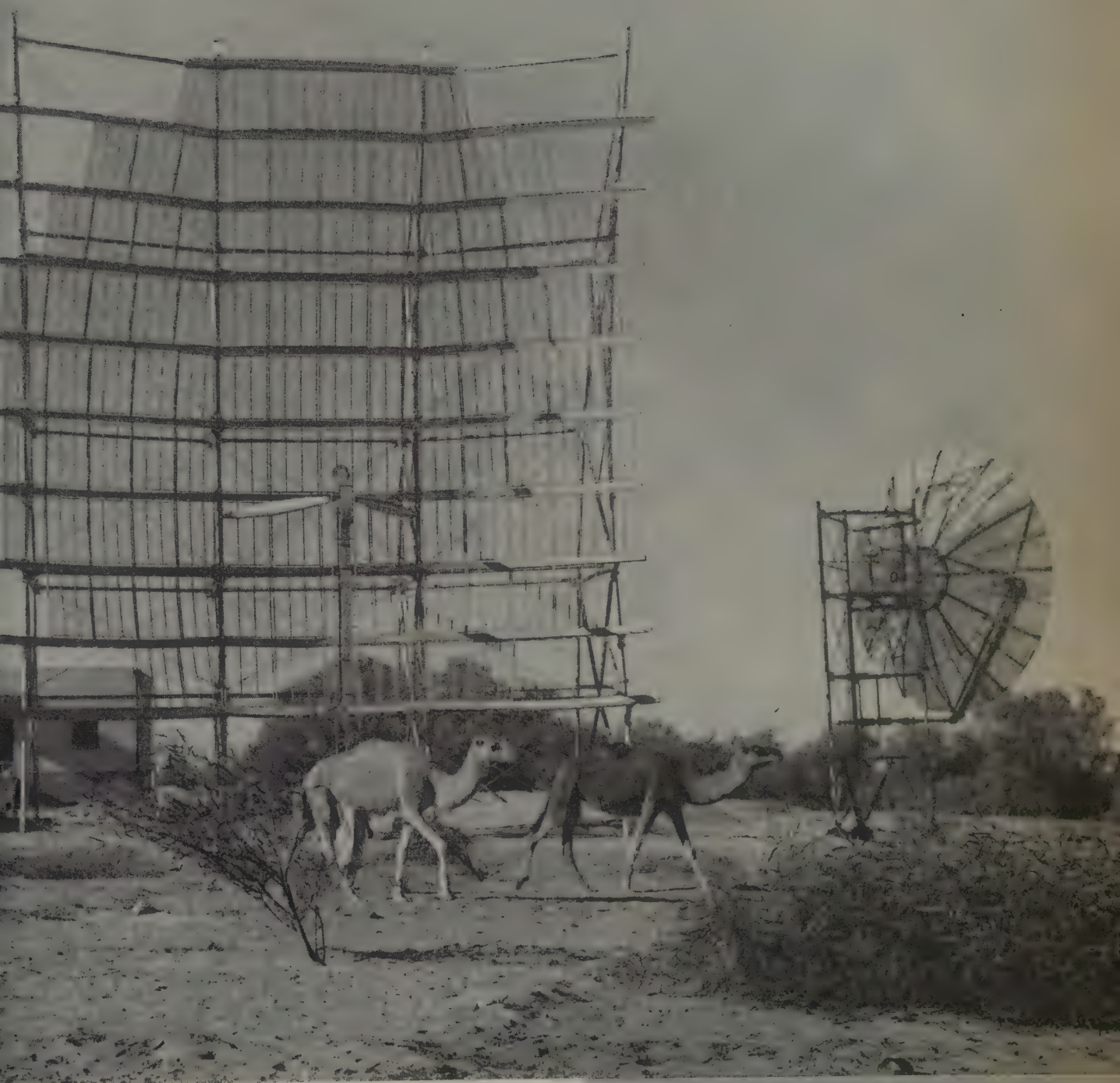
❖

Kent J. Worthen (S'49–A'50–M'52) has been appointed to the newly-created position of manager of product planning for point-to-point communication at General Electric Communication Products Department's national headquarters in Lynchburg, Va. Previously he was product planning manager for GE Microwave equipment. In his new position, Mr. Worthen will be responsible for long range market and product development guidance for power line carrier, microwave relay, and terminal communications products.

K. J. WORTHEN

(Continued on page 92A)

"OVER-THE-HUMP" SCATTER
ANTENNA BY KENNEDY



THESE CAMELS HAVE JUST WALKED A MILE to view the latest 60-foot steel and 28-foot aluminum antenna systems at a relay station in one of our overseas tropo scatter communications networks.

ANTENNA EQUIPMENT

D. S. KENNEDY & CO.

COHASSET, MASS. EVergreen 3-1200

Down-To-Earth **SOLUTIONS** *to Out-Of-This-World* **PROBLEMS**

Tracking Antennas
Radio Telescopes
Radar Antennas
"Trans-Horizon" Antennas
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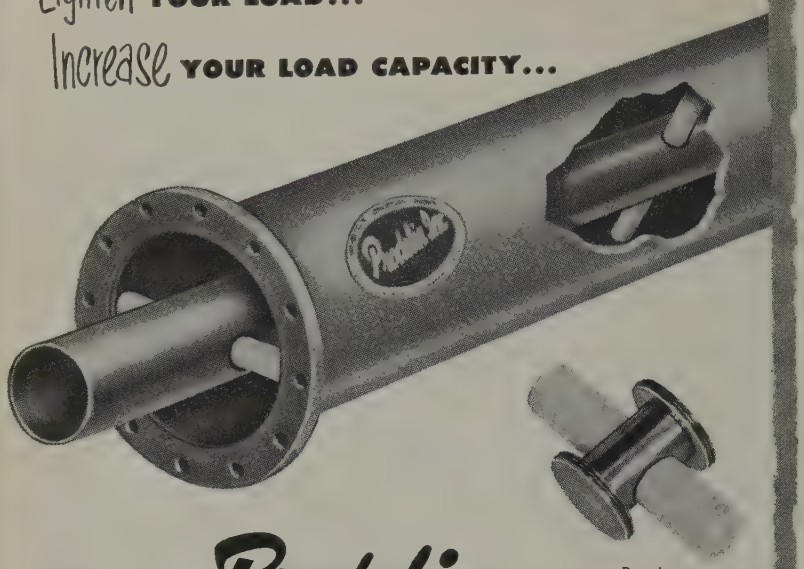
Lighten **YOUR LOAD...**
Increase **YOUR LOAD CAPACITY...**



Reactance Compensated Insulator

with New *Prodelin*

ALUMINUM

COAXIAL TRANSMISSION LINES and COMPONENTS

Available now . . . rigid aluminum transmission line and components that comply fully with EIA and Military Specifications TR-134 and MIL-L-3890. The copper inner conductor is supported by Prodelin's patented reactance compensated teflon pin insulators; compensated anchor insulators are also used throughout.

The aluminum outer conductor provides strength and corrosion resistance together with lightness of weight and handling ease.

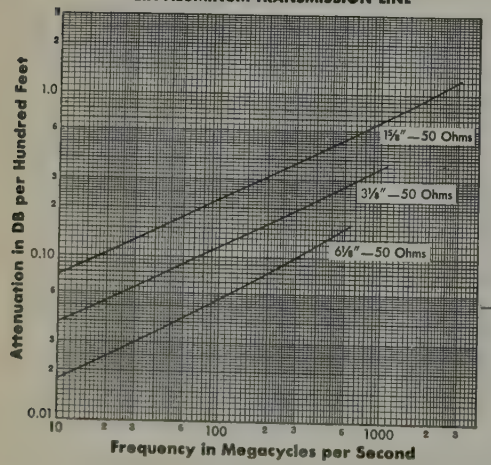
Available in sizes 1⅝", 3⅛", and 6⅛" — 50 ohm impedance.

FOR MILITARY AND COMMERCIAL SERVICES

FEATURES

- **Highest Power Handling**
- **Low VSWR**
- **Performs up to 250°C**
- **Corrosion Resistant**
- **Constant 50 ohm Impedance**
- **High Tensile Strength**
- **Lightweight, Easy to Handle**
- **Minimum Maintenance Required**

ATTENUATION VERSUS FREQUENCY
EIA ALUMINUM TRANSMISSION LINE



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FOR TECHNICAL BULLETIN 589

ANTENNAS and TRANSMISSION LINES
Prodelin Inc
KEARNY, NEW JERSEY, U.S.A.

Dept. I-6
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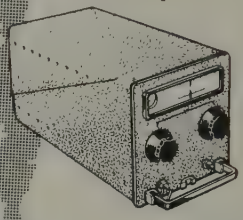
Manufacturer of the World's Finest Air Dielectric Transmission Lines, Connectors, and Associated Components

A.W.A

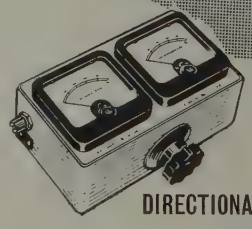
ELECTRONICS

New concepts in electronics have been developed at AWA, as a result of experience with missile systems. Now they have a wider application. Here are some of the new AWA devices now available to industry.



U.H.F. WIDEBAND RECEIVER

Basic arrangement consists of R.F. amplifier, mixer, local oscillator, I.F. amplifier (A.G.C. controlled), cathode follower output stage. Tuning indicator (EM 34) is also fitted to receiver. The standard forms: one for airborne racking with special separate power supply unit, the other on larger chassis including power supply unit (conventional 19" front panel). *Standard specification: 420-470 M/cs frequency range; 4 M/cs overall bandwidth, approximately 10 db noise factor; approximately 70 ohms input impedance, 200-250 V and 50-60 c/s input supply. Input is unbalanced, output is via low impedance (cathode follower) stage.*



DIRECTIONAL COUPLER

Of the 'Loop' type, suitable for measurements of RF power and Standing Wave Ratio in coaxial cables. Directional properties are largely unaffected by frequency changes, so coupler may be used to help obtain optimum termination of a 52 ohm coaxial system up to 600 M/cs. *Standard specification: Size 7" x 4" x 2½"; weighs 4 lbs. 3 ozs.; Power Measurement Range is Low range 1w.cw.max. High range 5w.cw.max.; less than 1% attenuation; better than 2% accuracy at frequency of calibration.*

All devices are adaptable to suit customers' own requirements. For further information consult:

COMMERCIAL ELECTRONICS DEPT.

SIR W. G. ARMSTRONG WHITWORTH AIRCRAFT LTD.
Baginton, Coventry, England
MEMBER OF THE HAWKER SIDDELEY GROUP

High Stability OHMITE® RITEOHM® PRECISION Metal Film Resistors

A new kind of precision resistor with these important features

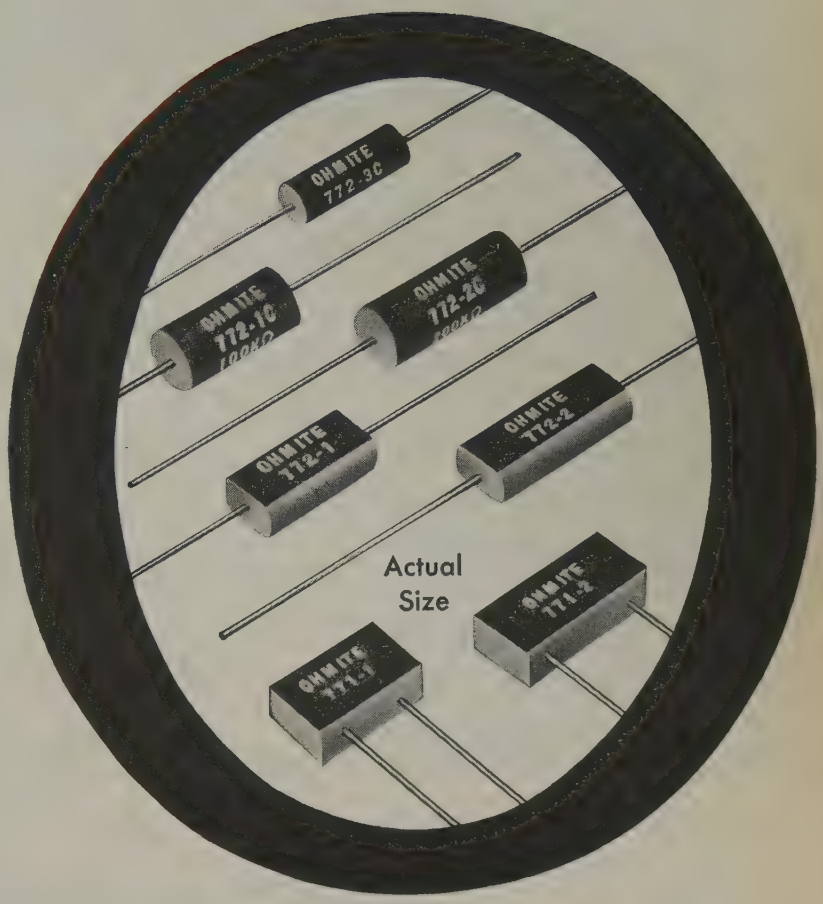
- Long-term load and shelf stability
- Low temperature coefficient of resistance
- Low noise level
- 125°C and 150°C ambient ratings
- Exceeds military specifications
- Excellent high frequency characteristics

Developed to meet tough new military and industrial demands, Ohmite Metal Film Resistors represent a radical departure in construction from wire-wound precision resistors. They employ no wire for the resistance element, yet feature stability and noise level comparable to wire-wound units. In addition, they have a low temperature coefficient of resistance, and excellent high frequency characteristics. Thus they are ideal for high-gain electronic circuits.

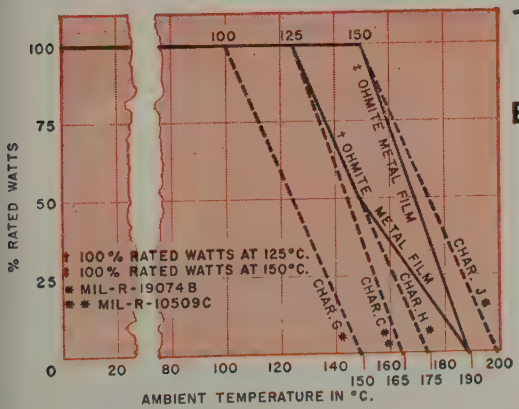
The expanded line of Ohmite Metal Film Resistors now consists of 5 sizes, and a total of 3 styles —full cylindrical, semi-cylindrical, and rectangular. With the new and existing sizes, Ohmite can now supply metal film units to meet various styles of MIL-R-10509C and MIL-R-19074B (Ships).

These new Metal Film Resistors may be used at full rated wattage in higher ambients than other types of precision film resistors. Wattage ratings range from ⅛ watt to 1 watt, depending on the resistor size and the ambient temperature. Ratings are based on two ambients—125°C and 150°C.

Temperature Coefficient of Resistance: Standard temperature coefficient is 0± 25ppm/°C (0± .0025%/°C) over a wide temperature range of −55°C to +190°C (25°C reference ambient) regardless of resistance value! Temperature coefficients of 0± 50 ppm/°C and 0± 100 ppm/°C are also available at lower cost. A temperature coefficient spread of 30 ppm/°C can be supplied at additional cost.



Write for Bulletin 155



Watt rating chart. These curves indicate percentage of rated wattage that can be applied at temperatures higher than 125°C and 150°C. However, at no time shall the applied voltage exceed the maximum for each style.

Be Right with OHMITE® Quality Components

Ohmite Manufacturing Company
3617 Howard Street
Skokie, Illinois

RHEOSTATS RESISTORS RELAYS
TANTALUM CAPACITORS TAP SWITCHES
VARIABLE TRANSFORMERS R. F. CHOKES
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no matter how INTRICATE your small space problem...

it can be solved with

MUCON

SUBminiature ceramic capacitors

in 12 versatile ceramic materials

CONCENTRATION on subminiature ceramic capacitors only, has enabled MUCON to develop this art to the highest degree of versatility . . . dependability . . . properties . . . shapes . . . to fulfill any critical requirement in subminiature size.

MUCON's custom facilities are geared to an

"IMMEDIATE SERVICE"

policy no matter the quantity.

Send for catalog/representative.

MUCON CORPORATION
9 ST. FRANCIS ST., NEWARK 5, N.J.

IRE People

(Continued from page 88A)

He joined General Electric Company in 1949 after receiving the B.S. degree in electrical engineering from the University of Utah. From 1951 to 1956 he was district sales manager for GE mobile radio equipment at Los Angeles, California, where he was chairman of the Los Angeles Chapter of the IRE Professional Group on Vehicular Communications. In 1956 he was named market development manager for GE mobile radio with headquarters at Syracuse, N. Y., and was appointed manager of microwave product planning a year later.

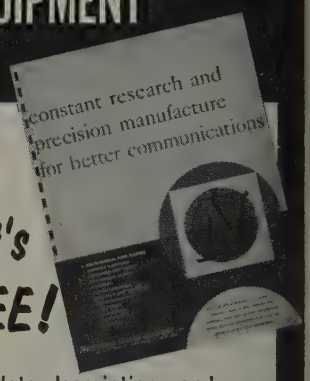
❖

Leonard Mautner (M'46–SM'47), former president of the electronic control systems division of Stromberg Carlson Company, has been appointed project manager for special systems by Hughes Aircraft Company. His work will concern new technical programs under study and application of the Hughes armament control systems to military aircraft used by certain friendly foreign nations.

Mr. Mautner, after an absence of five years, rejoined Hughes where he had helped in development of the Falcon series

(Continued on page 110A)

The new NORTHERN RADIO catalog is your buyers guide to FREQUENCY SHIFT COMMUNICATION EQUIPMENT



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for AC and DC measurements in the ultra-low current region

MODEL 201B
F. O. B. Oakland, Calif. $525

PRINCIPAL FEATURES OF THE E•H MODEL 201B ARE:

- High sensitivity; 16 ranges, 3 x 10^{-14} to 10^{-6} amps full scale
- Fast Response; Time Constant 40 μsec at 10^{-6} amps, 250 μsec at 10^{-9} amps, 400 millisec at 10^{-12} amps full scale
- Exceptional dc stability, ultra low grid current
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for additional information, write or wire...

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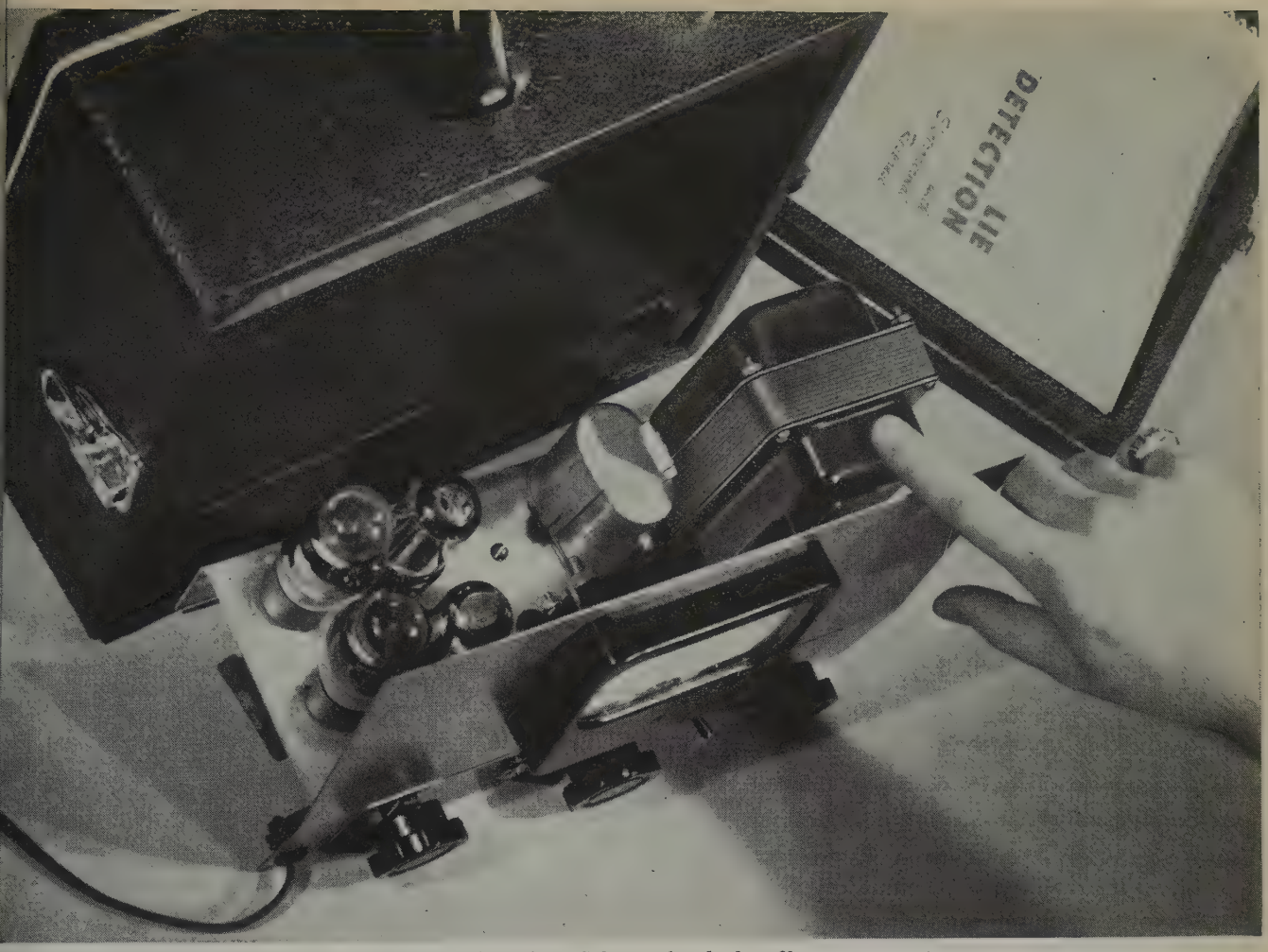
Electrometer Amplifiers • Millimicrosecond Coincidence Units • Millimicrosecond Pulse Generators



B & W Associates built in a Sola regulated plate-filament power transformer as an integral component in their portable lie-detection apparatus.

Portable lie detector operates accurately with Sola-regulated plate and filament voltages

This sensitive polygraph operates by picking up and immensely amplifying tiny electrodermal responses. It's small wonder that line voltage variations encountered in field operation must be corrected if the responses of the witness are to be measured accurately.

The lie detector's built-in power supply transformer is a Sola Constant Voltage Plate-Filament Transformer which performs this dual function: (1) it supplies plate and filament voltages just as an ordinary power supply transformer would do; (2) it regulates these supply voltages within ±3% even when the line voltage varies over a 100 to 130-volt range.

Besides providing regulation which assures accurate polygraph operation, the Sola transformer protects tubes and components from cold inrush current and from fault currents.

This simple, reliable component costs little more than ordinary, non-regulating transformers. And compared to other types of regulating circuitry used with conventional power transformers, it is considerably cheaper.

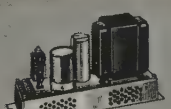
The plate-filament regulator is only one of the complete family of Sola Constant Voltage Transformers including such special types as filament and adjustable-output units. More than 40 models are available from stock, and Sola manufactures custom-designed units in production quantities to meet special needs.

For additional information write for Bulletin 1F-CVE

Sola Electric Co., 4633 W. 16th St., Chicago 50, Ill., Bishop 2-1414 • Offices in principal cities • In Canada, Sola Electric (Canada) Ltd., 24 Canmotor Ave., Toronto 18, Ont.

SOLA

CONSTANT VOLTAGE TRANSFORMERS


REGULATED DC POWER SUPPLIES

MERCURY LAMP TRANSFORMERS

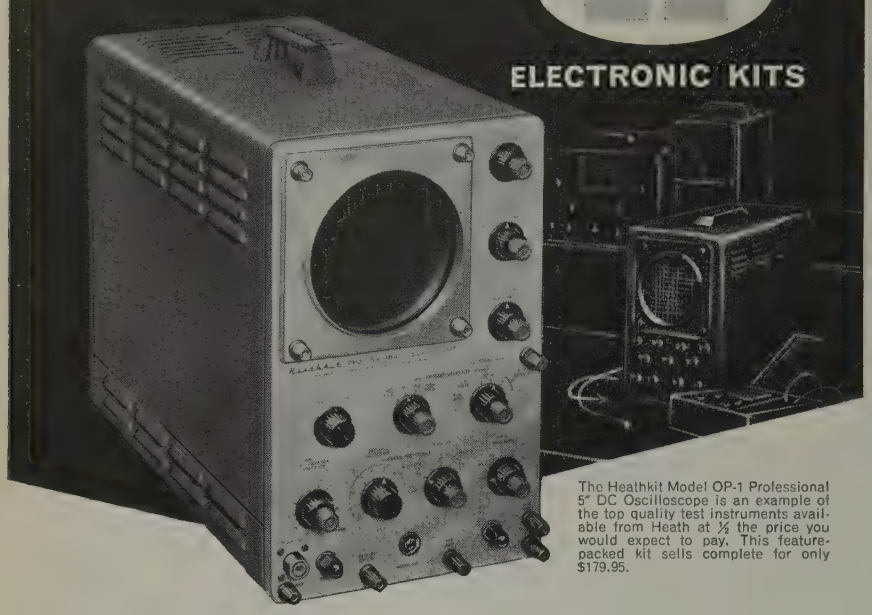
FLUORESCENT LAMP BALLASTS

A DIVISION OF BASIC PRODUCTS CORPORATION

CUT LAB EQUIPMENT COSTS IN HALF

HEATHKIT®

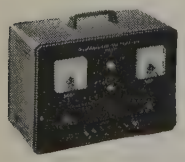
ELECTRONIC KITS



The Heathkit Model OP-1 Professional 5" DC Oscilloscope is an example of the top quality test instruments available from Heath at ½ the price you would expect to pay. This feature-packed kit sells complete for only $179.95.

Heathkits give you twice as much equipment for every dollar invested.

The Heathkit Model V-7A is the world's largest selling VTVM. Precision 1% resistors are used in the voltage divider circuit for high accuracy and an etched circuit board simplifies assembly and cuts construction time in half. Price of this outstanding kit is only $25.95.



The Heathkit Model PS-4 Variable Voltage Regulated Power Supply Kit is another outstanding example of Heath Company engineering ingenuity. Truly professional in performance as well as appearance yet it costs only $54.95.

Stretch your test equipment budget by using HEATHKIT instruments in your laboratory or on your production line. Get high quality equipment without paying the usual premium price by letting engineers or technicians assemble Heathkits between rush periods. Comprehensive step-by-step instructions insure minimum construction time. You'll get more equipment for the same investment and be able to fill any requirement by choosing from more than 100 different electronic kits by Heath. These are the most popular "do-it-yourself" kits in the world, so why not investigate their possibilities in your business. Send today for the free Heathkit catalog!

ALL PRICES F.O.B. BENTON HARBOR, MICH. PRICES AND SPECIFICATIONS ARE SUBJECT TO CHANGE WITHOUT NOTICE.

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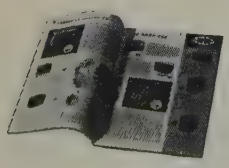

Mail the coupon today for the latest catalog describing over 100 easy-to-build, high quality electronic kits.

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a subsidiary of Daystrom, Inc.

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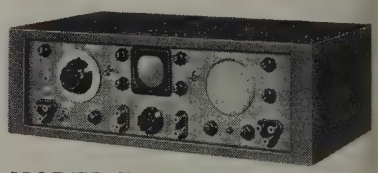
ACCURACIES BETTER THAN 1 PART IN 50 MILLION are free!

WHY NOT USE THEM!

The standard time and frequency transmissions of the National Bureau of Standards radio stations WWV and WWVH provide an invaluable service to laboratories and experimenters throughout the world. Extremely precise (normal transmission stability is within 1 part in 10^9 at WWV and 5 parts in 10^9 at WWVH) audio and radio frequency standards, as well as accurate time intervals and radio frequency propagation warnings, are placed at the disposal of anyone having a receiver capable of tuning to one or more of the transmitting frequencies. Proper use of these facilities can be made to supplement the instrumentation of any laboratory.

The Model WWVC Standard Frequency Comparator is just such an instrument . . . a highly sensitive crystal-controlled radio receiver utilizing WWV and WWVH transmissions.



MODEL WWVC
COMPARATOR

A 5-position dial switches *precisely* to any Standard Frequency—2.5, 5, 10, 15, or 20MC. It features built-in oscilloscope and speaker, comparator function selector, Collins plug-in filter for high selectivity, automatic gain and volume controls and adjustable threshold control which eliminates noise and other modulation in tick position.

Send for bulletin #557, "Using Standard Time and Frequency Broadcasts"

SPECIFIC PRODUCTS

Box 425, 21051 Costanso
Woodland Hills, Calif.

NEW FUSION-SEALED glass capacitors defy environmental stresses

Corning's NEW CYF Capacitors are guaranteed to be four times better than MIL specs require on moisture resistance.

Here are two new capacitors that are *practically indestructible* under severe environmental stresses.

For example the CYF's will withstand MIL-STD 202A moisture conditions for over 1000 hours with no signs of deterioration.

And you'll find that both the CYF-10's and CYF-15's do better on all counts for the specifications set forth in MIL-C-11272A.

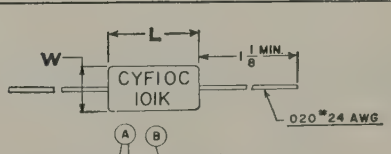
To make the CYF's impervious to environmental stresses, we've completely encapsulated the glass dielectric element in a glass casing. This encapsulation is completely fusion-sealed against moisture, salt, corrosion and weathering.

Here's the basic availability picture:

At 125°C. you can get CYF-10's in 5-150 uuf @ 500 VDC and 160-240 uuf @ 300 VDC.

At 125°C. you can get CYF-15's in 160-510 uuf @ 500 VDC and 560-1200 uuf at 300 VDC.

If you need high reliability and miniaturization, the CYF's—the only FUSION-SEALED Capacitors available—are worth looking into. For complete details, write to Corning Glass Works, 542 High Street, Bradford, Pa. Or contact our sales offices in New York, Chicago, or Los Angeles.



	CYF-10	CYF-15
L	$11/32 \pm 3/64$	$15/32 \pm 3/64$
W	$11/64 \pm 1/32$	$17/64 \pm 1/32$
T	$5/64 \pm 1/32$	$7/64 \pm 3/64$

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CORNING MEANS RESEARCH IN GLASS

FREQUENCY STANDARDS

PRECISION FORK UNIT
TYPE 50

Size 1" dia. x 3¾" H. Wght., 4 oz.*

Frequencies: 240 to 1000 cycles
Accuracies:—
Type 50 (±.02% at —65° to 85°C)
Type R50 (±.002% at 15° to 35°C)
Double triode and 5 pigtail parts required
Input, Tube heater voltage and B voltage
Output, approx. 5V into 200,000 ohms

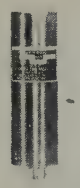
*3⅛" high
400 - 1000 cy.

FREQUENCY STANDARD
TYPE 50L

Size 3¾" x 4½" x 5½" High
Weight, 2 lbs.

Frequencies: 50, 60, 75 or 100 cycles
Accuracies:—
Type 50L (±.02% at —65° to 85°C)
Type R50L (±.002% at 15° to 35°C)
Output, 3V into 200,000 ohms
Input, 150 to 300V, B (6V at .6 amps.)

PRECISION FORK UNIT
TYPE 2003

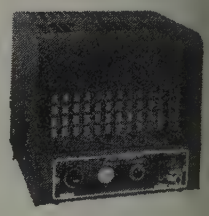


Size 1½" dia. x 4½" H. Wght. 8 oz.*

Frequencies: 200 to 4000 cycles
Accuracies:—
Type 2003 (±.02% at —65° to 85°C)
Type R2003 (±.002% at 15° to 35°C)
Type W2003 (±.005% at —65° to 85°C)
Double triode and 5 pigtail parts required
Input and output same as Type 50, above

*3½" high
400 to 500 cy.
optional

FREQUENCY STANDARD
TYPE 2005



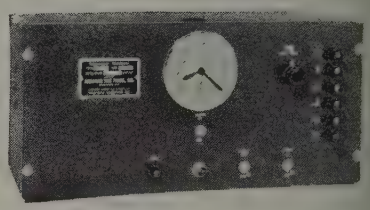
Size, 8" x 8" x 7¼" High
Weight, 14 lbs.

Frequencies: 50 to 400 cycles
(Specify)
Accuracy: ±.001% from 20° to 30°C
Output, 10 Watts at 115 Volts
Input, 115V. (50 to 400 cycles)

FREQUENCY STANDARD
TYPE 2007-6 *NEW*

TRANSISTORIZED, Silicon Type
Size 1½" dia. x 3½" H. Wght. 7 ozs.
Frequencies: 400 — 500 or 1000 cycles
Accuracies:
2007-6 (± .02% at —50° to +85°C)
R2007-6 (±.002% at +15° to +35°C)
W2007-6 (±.005% at —65° to +125°C)
Input: 10 to 30 Volts, D. C., at 6 ma.
Output: Multitap, 75 to 100,000 ohms

FREQUENCY STANDARD
TYPE 2121A

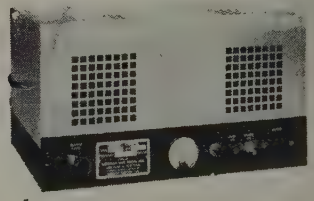


Size
8¾" x 19" panel
Weight, 25 lbs.
Output: 115V
60 cycles, 10 Watt
Accuracy:
±.001% from 20° to 30°C
Input, 115V (50 to 400 cycles)

FREQUENCY STANDARD
TYPE 2001-2

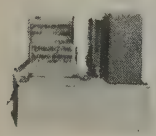
Size 3¾" x 4½" x 6" H., Wght. 26 oz.
Frequencies: 200 to 3000 cycles
Accuracy: ±.001% at 20° to 30°C
Output: 5V. at 250,000 ohms
Input: Heater voltage, 6.3 - 12 - 28
B voltage, 100 to 300 V., at 5 to 10 ma.

FREQUENCY STANDARD
TYPE 2111C



Size, with cover
10" x 17" x 9" H.
Panel model
10" x 19" x 8¾" H.
Weight, 25 lbs.
Frequencies: 50 to 1000 cycles
Accuracy: (±.002% at 15° to 35°C)
Output: 115V, 75W. Input: 115V, 50 to 75 cycles.

ACCESSORY UNITS
for TYPE 2001-2



L —For low frequencies
multi-vibrator type, 40-200 cy.
D—For low frequencies
counter type, 40-200 cy.
H—For high freqs, up to 20 KC.
M—Power Amplifier, 2W output.
P —Power supply.

This organization makes frequency standards within a range of 30 to 30,000 cycles. They are used extensively by aviation, industry, government departments, armed forces—where maximum accuracy and durability are required.

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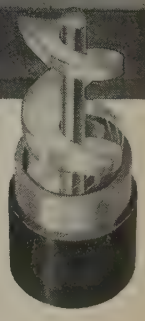
580 Fifth Ave., New York 36, N. Y.

New space-scanning radio telescope equipped with *Styroflex® Coaxial Cable*



Styroflex® coaxial cable is an important component part of the new radio telescope now in operation at the National Radio Astronomy Observatory, Green Bank, W. Va. This remarkable telescope is designed to probe the universe for radio waves originating in space.

Six "runs" of Styroflex® coaxial cable connect the 85-foot parabolic antenna with the control building. These "runs" are used to relay radio waves picked up from outer space by the telescope.

The job of feeding these low-energy radio waves to the control center calls for a high frequency cable with a low inherent noise level. The low loss and low noise to high signal ratio of Styroflex® cable provide the ideal answer to these operational requirements. An additional advantage is the long operating life of this coaxial cable, regardless of climatic conditions.

The superior properties of Styroflex® cable have earned for it an outstanding reputation in high frequency cable applications of many different kinds. If you have a problem requiring the use of a high frequency cable with exceptional characteristics, perhaps Styroflex® can provide the answer.

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The Applied Physics Laboratory
of
The Johns Hopkins University

Announces Appointments
for
SENIOR SCIENTIFIC STAFF

The Assessment Division of The Applied Physics Laboratory has undertaken new responsibilities and is expanding its Senior Analytical Staff. Senior Scientists in such fields as Mathematics, Physics and Physical Chemistry have in the past proven very effective in solving the types of problems involved which include analyses of tactical situations, the employment of future weapon systems and the application of the most recent advances in science and technology.

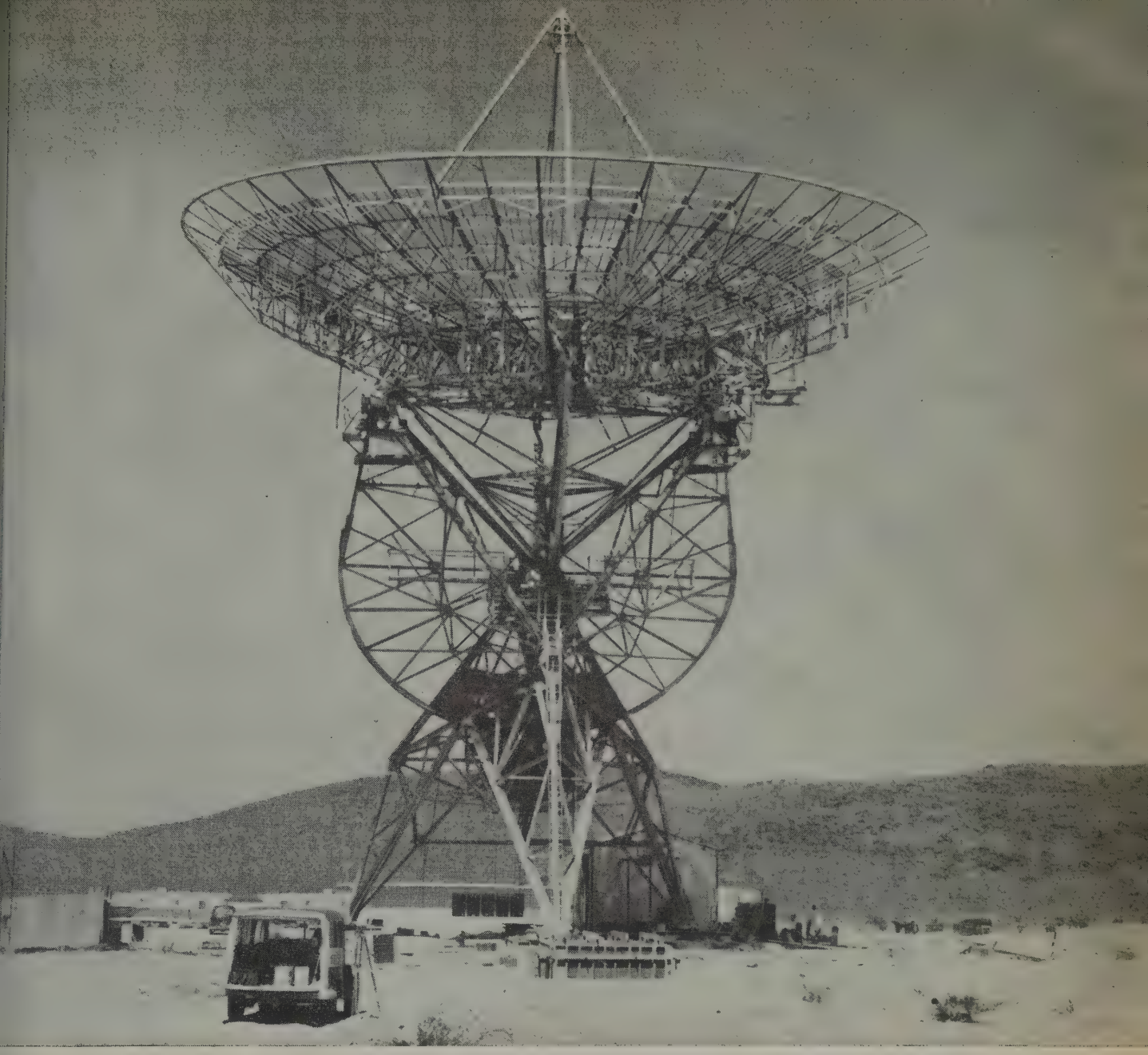
Performance of the work requires close association with scientists of other laboratories, operations research personnel of all branches of the Armed Services, and with senior military and civilian personnel.

Studies undertaken by this group will provide guide lines for the hardware research of future years. Staff members are expected to initiate ideas in support of a broad program of National Defense needs and carry them through appropriate analyses with assurance that sound results will be given consideration by the responsible agencies.

The Laboratory's locale, equidistant between Baltimore and Washington, D. C., allows staff members to select urban, suburban or rural living and either of these two outstanding centers of culture as a focal point for fine living.

These appointments offer exceptional opportunities. For information and arrangements for interview, write in confidence to:

Dr. Charles F. Meyer
Assessment Division Supervisor
The Applied Physics Laboratory
The Johns Hopkins University
8603 Georgia Avenue
Silver Spring, Maryland



85′ diameter tracking antenna, shown under construction. Reflector face surface is fabricated from aluminum. Pedestal, Polar Cage, Declination Cage and back up structure are of galvanized steel.

New BLAW-KNOX 85′ diameter tracking antenna for U.S. Lunar Probe Project

This newest Blaw-Knox 85′ Tracking Antenna is part of the Space Probe Project of the Jet Propulsion Laboratory at Pasadena, Calif. It will be used to maintain communications with space vehicles at ranges up to 250,000 miles.

Its design is fully determinate. All structural members of the assembly are analyzed for stress and deflection before fabrication. Coupled with shop fabrication and field erection to rigidly accurate tolerances, it is capable of the highest gain, with a minimum of distortions or aberrations.

The entire drive system embodies such critical design requirements as infinitely variable movement with negligible creep or overrun for tracking. The slewing drives are capable of the extremely rapid acceleration and deceleration necessary to focus on targets.

Pioneering like this is the latest step in a long series of Blaw-Knox developments. Such milestones as the Guyed Vertical Radiator design in AM radio, the first radar antenna used to bounce signals off the moon, and the Tropospheric Scatter Antenna for over-the-horizon television have marked Blaw-Knox as a world leader in advanced design, fabrication and erection techniques.

Blaw-Knox welcomes the opportunity to translate your most advanced concepts into highly reliable operating equipment. Contact the Antenna Group.

Antennas—Rotating, Radio Telescopes, Radar, Tropospheric and Ionospheric Scatter.

BLAW-KNOX

BLAW-KNOX COMPANY

Blaw-Knox Equipment Division

Pittsburgh 30, Pennsylvania

THIS TUBE THRIVES ON HIGH VOLTAGE!

RCA-1B3-GT is designer-preferred...features heavy-duty filament...challenges filament burnout

Preferred Tube Type 1B3-GT is favored by design engineers for high-voltage rectifier service in TV sets. What makes it so good? How was RCA able to make it better?

A redesigned filament of larger wire with a larger coil diameter offers cooler operation. A smoother and lighter coating to assure uniform emission is applied to the filament by means of a special technique. The life of the filament is further safeguarded by a chemically treated anode support which assures a tight bond between it and the glass envelope and prevents leaks that would burn out the filament.

The glass envelope of the RCA-1B3-GT has benefited, too, from improved techniques. Hydrogen firing of the envelope enables it to withstand electron bombardment and therefore reduces strain effects. In addition, contamination and resultant low emission are eliminated by supersonic washing of the anode and getter shield.

That's why the RCA-1B3-GT is a "champion" with high voltages. Your RCA Field Representative has the complete Preferred Tube Types story. See him soon.

If picture tubes are your interest, consider RCA here, too, for RCA picture tubes are engineered for long dependable performance. A word to your RCA Representative will bring you full information.

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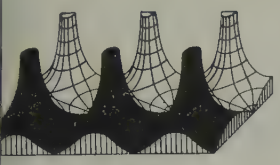
RADIO CORPORATION OF AMERICA
Electron Tube Division *Harrison, N. J.*

June, 1959
Vol. 47 No. 6

Proceedings of the IRE

Poles and Zeros



DX and Progress. On March 6, Pioneer IV, our first artificial asteroid established what appeared as an all-time dx record transmitting its last usable signal at a distance of 410,000 iles toward the sun. Soon thereafter we learned of the earlier aiseworthy work done in February by the Lincoln Laborary group, in aiming a radar signal at Venus and receiving e return at a round trip distance of 56,000,000 miles.

We recall a day when even terrestrial DX was an event, id well remember sitting in while our local DX achiever conected Brazil using a 199 tube and 0.2 watt plate input for a enomenal record of 30,000 miles per watt. Being in the 199 ays (a type now so obsolete it is not even on the Not Recomended list) it was also much before we had uncovered Hart's law, although we knew well the Hartley oscillator, when e knew of bands but not bandwidth, and utilized antennas signed and placed according to the limits of the real estate stead of the requirements of impedance, gain, and direcvity. And then the receiving equipment used therewith was TRF, blooper detector, and one step with Baldwin cans (if ou really were in the bucks).

With such a background, and many of us have it or can ceed it in historical interest, it helps our egos to note that th 265 kilowatts announced power at 28,000,000 miles one ay to Venus, the Venus experiment succeeded in reaching e figure of 105 miles per watt! The little old 199, pulsed th good honest ham CW, can apparently still claim the title, not surpassed by modern transistors. We admit, of course, at it is harder to hit a rabbit with a rifle than with a shotn, and the high-power radar at Millstone Hill, Massachutts, is a rifle and Venus is no rabbit, being more of a sitting ack!

It probably should be overlooked in passing, but we like gures well enough to bring out the fact that the system loss proximated 150 db. The system transmitted a pulsed signal r 4.5 minutes, and it took several months to statistically etermine that a return signal had been received. Such a signal presents essentially one bit of information (did or did not), that we suspect some sort of record may have been set in rms of channel capacity utilized per bit.

All the above is but prologue to our main thesis upon hich we set out in writing this column—that in the field of ectronics engineering, application no longer trails basic rearch by many years. In fact it would appear that the large d diversified basic research, plus the close relations and inparable nature of much of our research and engineering delopment has had available the methods, systems, or equipment when the need arose, or that invention must no longer wait upon necessity. Cannot we even say today that when necessity arrives, invention is here to meet it?

Take our recent timid ventures into space—could these have even passed the stage of science fiction without the computer for solving navigational problems, without the transistor and printed circuits for miniaturization, without the radar and radio astronomy antennas for communications? Was the computer developed after its need in a space program became apparent? Was the transistor a result of a program to reduce the size and power input of communication devices for satellites? Were our massive controllable antennas designed and built to track a midget aluminum sphere at an insignificant distance in space?

The answers are obviously negative; the computer was a result of a desire of thinking men to solve more problems faster, the transistor a stop along the way in a major attempt to understand better the nature of electrical materials, and our antennas were a product of basic and pure research into the far reaches of interstellar space. Yet when needed they were ready.

Our conventions, exhibits, and symposia give some evidence that we may be stockpiling other developments for which present application is unclear, toward a day when another new challenge arises—perhaps direct electrical conversion of fusion energy? Can we hope through intensive and close coordination of engineering with research, to provide the tools before the need and thus more quickly master nature for mankind's benefit?

We Grow Again. Once more we take this opportunity to welcome new IRE Sections: the Benelux Section of Belgium, the Netherlands, and Luxembourg; the Milan, Italy, Section; and that in Orlando, Florida, U.S.A.

This action brings to 103 our total of Sections, of which eight are located outside the United States and Canada. The old timer in this group is Buenos Aires, established in 1939; the others include Israel, Egypt, Tokyo, Rio de Janeiro, Colombia, Benelux, and Milan which have been founded since 1954.

We greeted our most recent foreign section, that in Quebec, in French in these columns, but because of the diversity of languages represented in our new Sections we are going to ask their indulgence for a greeting in English.

We are indeed glad to see this increased interest in international electronics. Good luck, Benelux, Milan, and Orlando.

—J.D.R.

Ferdinand Hamburger, Jr.

Director at Large, 1959–1961

Ferdinand Hamburger, Jr. (A'32–M'39–SM'43–F'53) was born in Baltimore, Maryland, on July 5, 1904. He was educated in the public school system of that city, and received the degrees of Bachelor of Engineering in 1924 and Doctor of Engineering in 1931 from The Johns Hopkins University, where he was a Charles A. Coffin Fellow in 1930–1931.

During the period between the undergraduate and graduate degrees he participated in a program of dielectric research at The Johns Hopkins University. In 1931 he was appointed instructor in electrical engineering; in 1947, professor of electrical engineering; in 1954, chairman of the department of electrical engineering; and in addition, in 1958, director of the Radiation Laboratory of The Johns Hopkins University. He served as chief test engineer for Bendix Radio Division from 1942 to 1945 while on partial leave of absence from the University. He has acted as consultant for the Research and Standards Section, Bureau of Ships, Navy Department; United States District Court; and The Radio Corporation of America; and others. He ha served as research contract director of a number of researc investigations supported by the Department of Defense a The Johns Hopkins University.

Dr. Hamburger joined the IRE in 1932 and was mad a Fellow in 1953. He was Regional Director of the Centra Atlantic Region in 1950–1951 and has served on the Nom inations, Appointments, Policy Advisory, and Educatio Committees. He has been a member of the Editorial Boar since 1956 and was vice-chairman in 1958. He was IRE representative at The Johns Hopkins University from 194 to 1955. He was largely responsible for the formation of th Baltimore Section in 1939 and its reorganization in 194 he served as its chairman in 1940–1941.

He is a Fellow of the American Institute of Electric Engineers and is presently serving as vice-chairman of i Instrumentation Division. He is a member of the Society Sigma Xi, Tau Beta Pi, and Eta Kappa Nu and is a regi tered Professional Engineer in the State of Maryland.

canning the Issue

IRE Enters Space (Berkner, p. 1048)—On March 25 at annual IRE banquet, over 1000 members and guests sat llbound while a distinguished radio physicist described the rmous opportunities which the space age has placed in the nds of the electronics profession. His speech ranged over ny topics—astronomy, physics, relativity, meteorology, mmunications, international planning—but always with ctronics in the central role. He discussed in particular the ssibility of using satellites, hovering some 22,000 miles ve the equator, as microwave relays for global communi-ions, providing a timely sequel to the description of passive ellites which appeared in these pages just two months ago. recapture for its readers the full impact of this memorable ed, PROCEEDINGS has discarded its traditional formality favor of publishing a tape recorded transcript of the talk its original, eloquently informal style.

Relativity and Space Travel (Pierce, p. 1053)—Lunik and oneer IV have brought man to the threshold of interplane-ry travel at speeds that are a significant fraction of the speed light. In escaping from his planet, man will also be leaving s familiar Newtonian world and entering a relativistic one which time, distance and mass are no longer absolute and variable nor everywhere the same, but instead depend on e relative velocities of the observer and the observed. nce the electronics engineer will be intimately concerned th man's exploits in space, it is highly desirable that he have me understanding of the subject of relativity as it applies problems of space flight and that he be aware of the pitfalls reasoning, such as the famous clock paradox, into which hers have repeatedly fallen. This understanding is now early provided by a unique and highly readable paper in hich readers will find the answers to the following interesting estions: 1) Since a clock runs slower at velocities near the eed of light, does this mean that if one twin took a long ace voyage at very high speed he would be several years unger than his earthbound twin when he returned? 2) ithin the next year or two a very precise clock will be placed a satellite and compared with one on earth. What do we pect this comparison will show? Why should a 2000-mile bit be avoided? 3) Photon rockets have been suggested for taining a speed very close to that of light. Will they really o that fast? 4) What about using space ships propelled by he energy of interstellar matter? How fast would they travel?

A Maser Amplifier for Radio Astronomy at X-Band (Giordmaine, *et al.*, p. 1062)—This paper reports one of the first major applications of the maser. Using a three-level ruby maser as a preamplifier, the U. S. Naval Research Laboratory has been studying microwave radiation from Venus, Jupiter and other radio sources since April of last year, with a resulting twelvefold improvement in sensitivity. The effective input noise temperature, including background radiation into the antenna, was found to be 85°K. This work demonstrates not only that the maser has substantially improved the performance of radio telescopes, but that it should be possible to reduce noise temperatures to nearly 10°K, resulting in even more dramatic improvements in the future.

Tantalum Printed Capacitors (Berry and Sloan, p. 1070)—The authors have found a way of applying a metal electrode, instead of an electrolyte, directly to a tantalum oxide film without creating short circuits or low breakdown strengths. This represents an important step forward because it makes possible the manufacture of the highly regarded tantalum capacitor by printed circuit techniques—a development of substantial significance at a time when microminiaturization is of such widespread interest.

Linear Diversity Combining Techniques (Brennan, p. 1075)—It is unlikely that two signals, separated in space, frequency, time, or polarization, would fade together. This fact has provided communications engineers with a powerful tool for overcoming the effects of fading, by using two or more separated transmission channels. This paper is concerned with current techniques for selecting or combining the two or more signals after they are received so as to improve the quality or reliability of reception. The author explains the fundamental concepts involved, clarifies earlier work on the subject, presents important new results, and provides extremely useful comparisons of the three most promising signal-combining techniques now in use. This much-needed work is the most comprehensive, the most unified, and the most clearly written treatment of the subject that has yet been published. It appears with the blessings of the PGCS.

Physical Principles of Avalanche Transistor Pulse Circuits (Hamilton *et al.*, p. 1102)—This paper presents for the first time a simple and straightforward theory which explains, to a good degree of accuracy, the operation of a transistor in the avalanche region. Since avalanche transistors have recently been found to provide a new and simple way of generating millimicrosecond pulses, this development will be of importance to those who are working in high-frequency pulse circuitry as well as those in the field of semiconductor devices.

Pulse Amplification Using Impact Ionization in Germanium (Steele, *et al.*, p. 1109)—Millimicrosecond pulses and avalanche phenomena, described theoretically in the preceding paper, are the subject of important new experimental work in this paper. Moreover, the avalanche process in this instance is produced by means of a new physical phenomenon found to occur when impurity-type semiconductors are subjected to extremely low temperatures (about 4°K), involving the rapid ionization of neutral impurity atoms under the influence of small electric fields. The pulse amplifier which the authors describe is believed to be the first solid-state device which operates on this principle.

The Transpolarizer: An Electrostatically Controlled Circuit Impedance with Stored Setting (Pulvari, p. 1117)—Recent improvements in ferroelectric materials have made it feasible for the author to devise a novel storage, switching and control element, consisting of two or more ferroelectric dielectrics connected in series. In addition to having many of the properties and functions of magnetic devices such as the transfluxor, the transpolarizer shows promise of finding use in solid-state display devices.

Geometric-Analytic Theory of Transition in Electrical Engineering (Bolinder, p. 1124)—The author shows how some well-known concepts in modern geometry may be applied to plotting the trajectories of circuit parameters in the complex plane, affording an interesting approach to frequently occurring circuit theory problems.

A Phenomenological Theory of the Reggia-Spencer Phase Shifter (Weiss, p. 1130)—This paper looks into the interesting question of why the behavior of a novel ferrite phase shifter, described in these pages a year and a half ago, differs so radically from the familiar Faraday rotation devices. The simple terms in which the analysis is carried forward not only aids in understanding this device, but may eventually lead to producing other novel effects in ferrites.

A New Look at the Phase-Locked Oscillator (McAleer, p. 1137)—This paper is aptly titled. It deals with a versatile device that has been looked at many times in the past, but never with such a freshness of viewpoint nor in such understandable terms. Little more could be added here that is not already clearly explained by the author.

Scanning the Transactions appears on page 1164.

IRE Enters Space*

L. V. BERKNER†, FELLOW, IRE

Summary—Man's escape from the confines of his planet offers him revolutionary opportunities for performing whole new ranges of scientific experiments, notably in such fields as astronomy, physics and geophysics. Electronics, because it provides the vital nerve system for such experiments, will be at the very center of these new exploits in space. Moreover, earth satellites, possibly in a 24-hour equatorial orbit, promise to open a new era in global communications in which almost limitless bandwidths may become available at relatively low cost.

Space will become a major part of the activities of the IRE and its members in the future. Already there is developing a need for international planning of space-age communications standards and of regulations for utilizing satellites for man's greatest benefit.

Introduction

IT WAS just forty-seven years ago, in 1912—within the span of most of our lifetimes—that Jack Hogan, Robert Marriott, and Dr. Alfred N. Goldsmith came together here in New York to form the Institute of Radio Engineers. In this short interval have come the great strides in technology that electronics has wrought. Indeed, we in the IRE have the opportunity to put our nose in almost everyone's business, because we supply the nerve system for almost every technology of which man can dream.

In the development of this vast technology, our Institute has played a very mighty part. The skill and the vision that has been required to organize this Institute so that the full power and strength of technology in electronics could bear on the problems of our country, has arisen from the vision and the dedication of the men that have led the IRE.

Among these, of course, we could cite the thousands of men who have worked on the committees of standards, who have worked on interengineering and industry committees such as JTAC, and who have organized and led our Professional Groups. But we must mention particularly our past Presidents who have carried the real responsibility for the organization and policy of this now greatest technical, or should I say quasi-scientific, society in the world. Among these Presidents I would particularly mention one man who can't be here tonight, and I am very sorry that he can't. His great leadership has led to the growth of the Professional Groups—those Groups which really carry much of the vitality of the IRE, which continue to make it grow in a solid and healthy technical fashion. I refer to Dr. W. R. G. Baker, who has long been a friend to all of us here in the IRE and who is also our Treasurer. Nor, of course, can we forget the people who have to do the day-by-day work, such as supervising publication of our wonderful journal, and the Editors of the PROCEEDINGS, and finally the men who run the basic organization underlying all of this—George Bailey, our great Executive Secretary, and Larry Cumming, our Technical Secretary.

This is the background that has prepared the Institute of Radio Engineers to enter into the space age that started scarcely more than a year ago. It was only on March 17th in 1958 that the first Vanguard satellite went up, the third of all of the satellites to be erected. It is still transmitting on one hundred-eight megacycles using solar batteries to power it, and one suspects that our grandchildren and perhaps even our great-grandchildren will be listening on that frequency to wonder a little about the exploits of our present generation. Tonight I will try to demonstrate to you that the future operations in space will become an important and ever a major part of the interests of this great Institute in the future.

Up to the year 1957 we were poor two-dimensional creatures who had to live on the surface of the earth. We couldn't escape above it, we couldn't get down very deep below its surface; we were confined like the ham in a sandwich and could only dream about what might happen if we could get to the outside. Now, we have gotten to the outside. We have seen for the first time the whole of the universe in the full range of its color. We can observe from the longest to the shortest wavelengths, from the highest to the lowest particle energies.

This escape is a bit reminiscent of the old story written by Mr. Abbott, the English schoolmaster, (I believe it was in the year 1848) when he described a two-dimensional world that he called "Flatland." In this two-dimensional world the people were two-dimensional geometric figures. Men could be triangles or squares or pentagons or hexagons, and if they were indeed very bright, they acquired so many sides that they finally became circles; whereas the women, as I recall it, were designated by straight lines (or really very narrow parallelograms). The story goes that one of the citizens of Flatland, a Hexagon, finally succeeded in escaping into three-dimensional space, and the story describes his wonder at the phenomena that he finds in three dimensions. Of course, Flatland was really a satire on the inability of men of the time to understand four dimensions. But it has unusual application in this day when we ourselves have just escaped into this three-dimensional world. Now, what is space going to mean to man in the future?

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Scientific Aspects of Space

Last night at the Symposium on Space you heard the scussions in which we mentioned that space science ould be an important aspect of space explorations. But ere will also be commercial and military applications. would repay us to look back just for a moment over e potentialities of science that can be done in space. deed, the important point is that we can now do sci- tific experiments that would be quite beyond our nge of capability without this opportunity to escape yond our atmosphere and on towards the planets, d perhaps eventually even toward some of the stars. The first science that comes to mind is the field of tronomy. Here one can imagine looking at the sun, r nearest star, not only in the ordinary spectrum, but wn into the ultraviolet, the X radiation, to really nderstand the physics of this variable body that gives s our energy, our light and heat. Already this is being one, and some of our distinguished members have pub- shed extraordinary papers in the Proceedings de- ribing our first views of the sun as we see it from be- nd our atmosphere—a truly revolutionary oppor- nity.

But, going on to the stars, one can anticipate that we ill learn much more of matter and its origin as we udy astrophysics with telescopes that can extend over e whole range of color. Already in radio astronomy e are planning to look at the very long wavelengths at the ionosphere obscures from us, and at the much orter wavelengths extending from a centimeter or so ght on down to the infrared. There will be a real chal- nge to the members of the Institute to produce meth- ds of detection in this intermediate range of wave- ngths that will permit observation in the range one entimeter to, say, fifteen mu. Then, finally, astron- mers will need new telescopes that can provide good efinition in the ultraviolet and X-ray regions of radia- ion.

Aside from the fun of these observations, one can retty safely predict that our new knowledge of the hysics of the universe, of its origin, its creation, its de- truction, will be extended immensely by this new pan- rama that we have of space.

Then one can turn to the field of physics. "Well," ou say, "what problems are there in physics that you an solve?" Let us take the case of general relativity. ou say, "But hasn't general relativity been proven rom the studies of the regression of the perihelion of Mercury?" The answer is that physicists would have aid so until a year or two ago, but ever since parity as general concept has tumbled down the drain, every- ne is prepared to question again very seriously the full enerality of some of the most fundamental concepts f our physics. Our operations in space permit us to nake a very clear and unambiguous test of the general heory of relativity by comparing a very precise atomic clock in a satellite with an identical clock on the earth. This experiment will be done in the next year or two. But beyond this, space science provides the opportunity to study fields, both gravitational and magnetic, on a scale involving new orders of distance in space. So, this escape into space really gives us a new dimension to carry on research in some of the most fundamental phenomena that occur in the field of physics.

In the field of geophysics, the advantages of space science are obvious. Last night you heard two distinguished physicists tell you of the studies that we are starting in the outer atmosphere, and beyond it in the region that lies between the outer atmosphere and the sun. I suspect that one of the most immediate rewards from studies in space will come to the field of meteorology. Remember that now our meteorologists can observe only about twenty per cent of the earth's surface —the rest is covered by oceans, the poles, and other inaccessible regions. However, with the satellite that we launched only last month, for the first time we can see and measure the cloud cover of the earth. It is hard to believe that up to the present time we have not known what proportion of the earth's surface is covered with cloud—we are just on the threshold of acquiring this information. We all know that the atmosphere of the earth behaves like the gas in a great heat engine that receives its heat generally in the vicinity of the equator and loses its heat near the poles. But changing cloud cover can change the heat balance—the input and output of energy of the heat engine—through reflection of solar radiation from cloud tops and absorption of terrestrial radiations in atmospheric gas dipoles. Soon we will know the distribution of the heat balance everywhere over the earth, so that we will have some opportunity to compute and to understand the performance of this heat engine which drives the gas of our atmosphere that gives us our weather.

Then, looking farther on, perhaps ten years or more, we begin to think of exploration of the moon and the planets. Among these I would mention Mars, Venus, Mercury, and perhaps the moons of Jupiter. It may be that ten, fifteen, twenty, or perhaps as long as fifty years hence, we will be sitting down to an IRE banquet with the spice on our meat from Mars, and I won't suggest what might come from Venus.

Communication by Satellites

In this space activity certainly electronics plays the key and central part. From the very experiment itself, in which electronics must always be the vital nerve center, to the storage where the information acquired must be stored for subsequent transmission back, through the telemetry system, through the beacons that locate the vehicle, through the systems of control—in every element of space activity our electronics physicists and engineers are involved in the game.

But in spite of the great importance of these general

aspects of space activity, we must turn to the basic question of space communications that will affect the interests of IRE most of all. Here we find a variety of applications that open Pandora's box—the basic opportunity for communication channels over long distances, perhaps a thousand, ten thousand, or even a million times beyond the opportunities that we have had heretofore. First of all, remember that when we transmit to and receive from satellites, we finally achieve the engineer's dream of having $1/r$ in the equation without having any exponent—for the exponent $e^0 = 1$. And I'll tell you that getting rid of this exponent does wonders for the engineer's good nature.

One can think of a variety of ways in which transmission and reception from satellites can be carried out to give us immense bandwidths for long-distance communications. Already you have read in the PROCEEDINGS, by John Pierce and others, the descriptions of how simple reflecting bodies sent into space—perhaps a hundred-foot sphere, perhaps a great corner reflector—can permit the relay of information by reflection from the satellite back to earth. Certainly these kinds of communications will be accomplished in the very near future—probably before this year is out. But, if you let your mind run just a bit further, you will realize that the real potentialities of communications from satellites lie in the receivers and amplifiers and transmitters that can be put in the satellites themselves. In this way, they provide you the opportunity to control very precisely as you choose, the kinds of communications you want to relay and the quality of those communications.

Someone said the other day, "Well, I don't suppose it will be worthwhile sending up a satellite for communications unless you have at least a two hundred megacycle bandwidth, or perhaps a five hundred megacycle bandwidth," and this is probably true. When you start to calculate power, you will say, "Oh, my goodness, we will never be able to do this with the power required to handle these wide bandwidths." But, with a little thought, you will realize that indeed you don't want very much power in the satellite; indeed a few milliwatts per kilocycle will do not only a very adequate job, it will also permit a much wider application of satellite communications than would an overpowering amount of output power. Indeed, one comes to the conclusion, with a little further study, that unless you keep the power down rather carefully, you can easily destroy the situation that you most want to acquire, and that is to realize cheaply the maximum number of transmission bands.

"Well," you will say, "what orbits must these satellites have in order to provide all of this communication? Should they be going around the equator, or around the poles?" The answer is, of course, one can select orbits to meet the requirements of a variety of situations. But, in thinking about the orbit, you pretty soon come to the conclusion that perhaps the most valuable orbit, the one likely to be most important, would be the so-called twenty-four hour orbit. Now, this is a very nifty satellite orbit—it is one in which the satellite is fired off to the eastward from the equator, or in fact from any other point and then is stabilized on an equatorial orbit. It is stabilized on the eastward orbit at just the right velocity, so that the satellite rotates around the earth just as fast as the earth itself turns. Then, of course, the satellite just hovers above a selected point above the equator or, if you haven't stabilized it on the equator, just oscillates slowly back and forth each twenty-four hours along a portion of the meridian, but always in your own plain view and control. Indeed, we should be able to launch a twenty-four hour satellite with suitable control in the very near future.

Now, when you have an object up there twenty-two thousand seven hundred miles (I believe that is what the oribital height comes out to be), and you control it pretty much over your head all the time, you can see that this can be a very useful device indeed. But, you say, "Well, after all, you put one of these things up there and then you have your two-hundred megacycles or your five-hundred megacycles, isn't that it?" But the answer, of course, is not as simple as that, because these electronics engineers are always clever fellows. They say, "Oh, but we would like to put some antennas around which are highly directive," and then instead of having one of these hovering satellites, we will have a hundred, perhaps a thousand, each one with a nice antenna looking at it. You can move your antennas a little bit, and because you know just where these satellites are, you can pick out the satellite you want, to bring in your connections with London or Moscow or Paris or whatever city you like. Then there will be enough megacycles bandwidth so each of us can have some.

I have described this in just a little detail to challenge your imagination with respect to the immense potentialities involved. Of course, the matter looks quite easy until you start to dig into the—you know—the nasty details. Then you discover that there are problems of position control and reliability, and above all, problems of terminal equipment on the ground. As far as power is concerned, it is beginning to look pretty good. Our solar cells seem to be doing all right, but more recently we hear a good deal of talk about the gas thermocouples (plasma thermocouples if you want to sound scientific), operated from small amounts of nuclear energy. It looks as though you would be able to supply all the satellite power you would want on a vehicle for a long time. So, one concludes that we are on the threshold of having made available to us at a relatively small cost, perhaps at a lower cost than any other form of long-distance communication, almost limitless bandwidths for point-to-point, or even in some cases mobile, communications.

One is only a bit frightened about the terminal equip-

ent and about man's capability to use this potentially st quantity of communications intelligently. How- er, at this Convention of the Institute we have learned at small solid-state circuits have come out that are rely larger than a pin-head. I believe I heard it said at five million such circuits could be put in a cubic ot. So you say, "After all, computers of any kind can e reasonably designed." Indeed, one is a bit startled to arn that computers, aside from ordinary program- ing, are now permitted to have judgment, and you n bring in whatever quantity or quality of judgment ou want into the computer operation.

The problems of cost, of course, inevitably come into he picture, and the cost of launching large rockets is ow very great indeed. But we must remember that in oing our initial rocket launching, we are a bit in the osition of an aircraft producer that wanted to get a ew aircraft. Every time he flew this aircraft it would rash, and from the crash he would have to determine he defects and then develop another aircraft that ould do a little better. This is precisely the situation n the rocket business. In spite of all the static testing, ne has to go through flight after flight during which our rocket crashes before you finally begin to get one hat is useful and effective.

I do not think one can be very critical of the people who have done a magnificent job of this rocket develop- ment. They are now perfecting our rockets to the point where they are becoming relatively reliable through elatively few test flights. I am told that within a very hort time a rocket that will put some four-hundred ounds into a suitable orbit can be launched for less han a half-million dollars. When you begin to calculate he kinds of communications that this will provide over a long period of time, you realize that the real cost per message unit lies not in the rocket and satellite itself, ut in the terminal equipment on the ground at both ends.

International Regulation

When we think about the problems of control, multi- plying our communications by a factor of a thousand or ten thousand or more over the present, one cannot help but be impressed with the dreadful problems that face the International Telecommunications Union, the International Frequency Board, the CCIR and our FCC in the future. I imagine that the present meeting of CCIR out at Los Angeles is beginning to worry about his pretty seriously, because rumors of the capabilities of these devices are just beginning to be discussed rather widely.

The question before us, with these potentialities im- mediately ahead, is how soon should we proceed with he standards—with the planning—that underlies an dvance in communications of this kind? To describe he thinking in some of the other countries, I am going o read to you from the minutes of the Technical Coun- cil of the Ministry of Communications, Moscow, held in January, 1959, and I quote a part of these minutes:

> S. I. Katayev pointed out that in the solution of a number of problems for the subsequent development of television technology, including the selection of the standards, it is necessary, even now, to take into account the possibility of utilizing the artificial Earth Satellite. It is also necessary to start to develop a series of concrete answers to problems, such as the transmitting and receiving radio equipment designed for several years' operation without servicing; the selection of an optimum wavelength for the cosmic retransmitter; automatic scanning of large antennas in cosmic space; sufficiently powerful, independent, long-duration power sources; investigation of the economic variants of color television designed to utilize the cosmic retransmitters; etc., etc.

It says further:

> Professor Katayev proposed to include the basic measures for realization of a cosmic television program retransmitter in the Seven-Year Plan for the development of the economy of the U.S.S.R.[1]

So, you see, that very serious thinking is going on abroad concerning the development of the means and standards required for the use of these immense potentialities for space communication in the future.

In the field of international planning, of course, we have the International Telecommunications Union and under it, all of its very excellent administrative and advisory bodies to deal with problems of frequency allocation. During the last session of the United Nations there was proposed a resolution which was adopted, but not unanimously, to have an international committee set up to study the general control, regulation and utilization of satellites for man's greatest benefit. Unfortunately, because of some disagreement over this, this committee has not yet been called together. But, I think all of you who have followed this problem would agree that it is rather urgent that man undertake early planning for this powerful new potentiality if it is to be used for his benefit and not for his detriment.

In the field of science, fortunately, all nations have joined in the scientific utilization of satellites under a committee called COSPAR, the International Committee on Space Research, organized and operating under the International Council of Scientific Unions. I am proud to tell you that at the last meeting of that Committee at the Hague, at which all important nations, including the U.S.S.R., were represented, the U.S. delegation was able to make a proposal which had been approved by our Government. This proposal invited scientists of nations outside of the United States, acting under COSPAR, to prepare selected experiments to be carried in U.S. satellites in the future. In my opinion this is a very wise decision on the part of our Government, since it means that scientists abroad whose science *must* be done in space in the future, will have access to that space through the good auspices of the United States. I believe that it is an offer of the greatest significance to our future.

[1] *Radiotekhnika*, Moscow, no. 1, p. 67; January, 1959.

Conclusions

In closing, I think we cannot avoid considering in this space age the implications of the race between ideologies in the world at the present time. True, we are in a military race, but beyond this the U.S. is really in a race for intellectual superiority. For, assuming that through wisdom we can avoid in one way or another a disastrous military conflict, then the future of the Western system depends upon the ability of the West to demonstrate the superiority of that system. If you try to avoid the implications of this race, you can not avoid the knowledge that if the U.S. is not racing with the U.S.S.R., at least the U.S.S.R. is racing with the U.S. I would read to you the closing remarks of Academician A. N. Nesmeyanov, the President of the Soviet Academy of Sciences, on the occasion of the first anniversary of the launching of the Sputnik. Nesmeyanov says:

> In marking the anniversary of the launching of the first artificial earth satellite, we may be confident that in the name of the great ideals of humanity our people, under the leadership of the Communist Party, will accomplish new and ever more notable feats.
>
> Our guarantee of this is the socialistic structure of our country, which gives wide rein to the development of science and ensures the bringing-out of the notable talents of our people.[2]

In the face of that position, can you doubt the Russian desire to achieve through their system intellectual superiority?

We have one great advantage, and that is the immense freedom that is enjoyed by each one of our citizens. This freedom challenges the individual, without being pressed by his government, to do his part in bringing the free society of men in which we live to a position of unquestioned leadership. For in a free system, it is the individual, not the government, that determines the competence of the system. In meeting this challenge, we in the Institute of Radio Engineers, who manage and control the nerve center of man's technology, are at the center of the affair. We cannot avoid it. It is something that is placed on our shoulders, and I do believe that this Institute, the men in it, the men who have created it, the men who will nurture its growth in the future, have the sense of responsibility, the spirit and the courage to meet this challenge—a duty that the free world delegates to them today.

I would finally say, with respect to the Institute itself, that rarely does a well-developed technology find an entirely new opportunity. But just such an opportunity, one that can multiply our communications a thousand times over, has been brought to us by space. Space promises cheap communications, international television, the opportunity for spreading good will if it is managed correctly. It promises a new order of acquisition and transmission of weather data, which may eventually lead to better forecasting and perhaps control or modification of our weather. Over the horizon are benefits which we can only imagine at the present time, for we are in the situation of Hexagon who has just escaped from two-dimensional space, and is still looking with wonder at the three-dimensional space around him.

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[2] "A great victory of Soviet science," trans. by E. R. Hope from *Vestnik Akad. Nauk SSSR*, vol. 28, no. 11, pp. 3–9; 1959.

Relativity and Space Travel*

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Summary—This paper treats in terms of the special theory of relativity: a "clock paradox" involving the fact that the frequency of an atomic oscillator on a moving body is lowered but the mass which is converted into radiation is increased; the case of the twin who goes on a space trip at near-light speed and returns younger than his brother on earth; the shift in frequency in the presence of a gravitational field; the clock rate on a satellite; the speed attainable by a photon rocket; and a space ship propelled by the energy of interstellar matter.

I. Introduction

TODAY engineers are building rockets and satellites with velocities unprecedented among gross, man-made objects. Further, they are seriously speculating concerning even higher velocities in connection with interplanetary travel. There have been repeated suggestions that a "photon rocket" could be used to attain a speed very close to that of light.

It is well known that the theory of Newtonian mechanics is inaccurate in dealing with velocities appreciable compared with the velocity of light. The solution to the problem of applying relativity consistently to the practical and speculative problems of space flight is less well known, and various questions and errors recur repeatedly.

Fortunately, it is possible to treat many interesting problems of space travel by means of special relativity, together with a few reasonable *ad hoc* assumptions. This is the purpose of the present paper. Portions of the material will be found in a number of sources.[1–5] A reasonably complete and unified account is attempted here.

Before we proceed to particular problems, a few general remarks may be helpful. In making use of relativity, it is important to avoid certain easy pitfalls. One of these is the notion of simultaneity. We make matters more difficult for ourselves, for instance, if in reckoning time on a space ship we talk about the time *on earth* at which the space ship turns around and heads toward earth instead of away from it. This can lead to a seeming "clock paradox" which will be discussed later.

Feynman has expounded the matter of simultaneity in a wonderfully simple manner. In pursuing his explanation we should note that, according to special relativity, an object going past us appears to be foreshortened in the direction of motion.

Imagine two very long starships, ships which to us are equally long, passing each other while traveling in opposite directions, as shown in Fig. 1. Suppose that just as they are opposite one another, two bolts of lightning pass instantly between them, one from the nose of the upper, leftward-traveling ship, which we will call ship L, to the tail of the lower, rightward-traveling ship, ship R, and the other from the tail of ship R to the nose of ship L. An observer in the center of the upper ship, ship L, will see the left-hand bolt first, because he tends to catch up with the light emitted by it, while he travels away from the light emitted by the bolt to the right. On the other hand, an observer in the center of ship R will see the light from the right-hand bolt first, for he rushes to meet the light from the right and flees the light from the left.

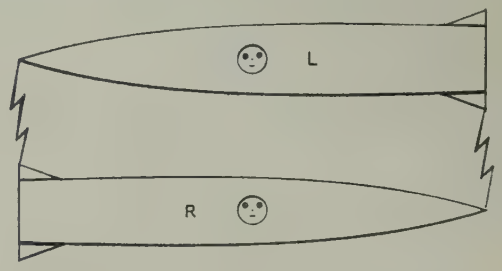

Fig. 1.

Special relativity tells us that the man in ship L has a perfect right to say, "*I* am standing still, and if I see the left-hand bolt of lightning, the one at my nose, before the right-hand bolt, the one at my tail, it is because the bolt at my nose occurred first. Indeed, it had to, for I see that that other ship, ship R, is much shorter than my ship, ship L, and hence his tail was opposite my nose before his nose reached the position of my tail."

On the other hand, the man in ship R says, "*I* am standing still. I saw the right-hand bolt, the one at my nose, first, and so it occurred first. Indeed, it had to, for that ship L is much shorter than my ship R, and his tail was opposite my nose before his nose reached the position of my tail."

Clearly, no argument can resolve this contradiction as to which bolt of lightning struck first, if, indeed, either did. An assumption of some instantaneous form of communication (telepathy, for instance) which enables us to determine a "true" time order of events would involve us in a hopeless paradox. We simply can't have such a thing and relativity too: one or the other must go.

* Original manuscript received by the IRE, April 1, 1959.
† Bell Telephone Labs., Inc., Murray Hill, N. J.
[1] J. H. Jeans and E. Whittaker, "Relativity," in "The Encyclopedia Brittanica," vol. 19, pp. 89–98, 1955.
[2] J. J. Coupling, "On atomic jets," *Astounding Science Fiction*, vol. 54, pp. 115–127; January, 1955.
[3] S. F. Singer, "Application of an artificial satellite to the measurement of the general relativity 'red shift'," *Phys. Rev.*, vol. 104, pp. 11–14; October 1, 1956.
[4] R. Schlegel, "New clock problems in special relativity," *Bull. Am. Phys. Soc.*, vol. 2, p. 239; April 25, 1957.
[5] C. G. Darwin, "The clock paradox in relativity," *Nature*, vol. 180, pp. 976–977; November 9, 1957.

As the relative velocities of the two ships approach the speed of light, one captain will insist that event A occurs a time L/c before event B, while the other insists that event A occurs at time L/c after event B, there will be a possible disagreement of $2L/c$ about what is simultaneous with what, where L is the length that each assigns to his ship. In general, for events occurring a distance L apart, there is a range of time $2L/c$ over which we cannot say whether one event occurred before or after another.

We can assert that event B at location b occurred after event A at location a, which is a distance L away only when a light signal generated by event A at a reaches b before event B occurs; this takes a time L/c. The same statement holds if we interchange A and a with B and b.

II. Some Equations of Special Relativity

It is not the purpose of this paper to derive the equations of special relativity. The purpose is to explain them sufficiently so that they can be used correctly and to apply them to certain problems in space travel.

The equations we need deal with an observer who considers himself to be standing still and a space ship, planet, solar system or galaxy which is moving past him, from left to right, with a velocity v. As we noted earlier, to the observer, all objects in the moving system appear to be shrunk or contracted by a factor which we will call a shrinking factor S. This factor is

$$S = \sqrt{1 - (v/c)^2}. \tag{1}$$

Here c is the velocity of light.

$$c = 3 \times 10^8 \text{ meters/sec.} \tag{2}$$

The moving object appears shrunk only in the direction of motion, not crosswise to it.

The clocks on the moving object also appear to be going slower by this same shrinking factor S, so that when our clock indicates the passage of one hour, the clocks on the moving system indicate the passage of only a fraction S of an hour.

Let us now consider the people in the moving system. One of them shoots a projectile in the direction of motion and says, "I have shot this forward with a velocity u_m." But, when we measure the velocity by our "fixed" standards, we obtain a velocity u

$$u = \frac{u_m + v}{1 + vu_m/c^2}. \tag{3}$$

We note that the velocity u which we observe can never be greater than c, the velocity of light. Suppose, for instance, that a man in the moving system shines a beam of light to the right, a beam which he says has the speed of light, so that $u_m = c$. Both he and the beam are rushing to the right, he with a velocity v. Yet, if we put $u_m = c$ into (3), we get for u simply c, the velocity of light. Eq. (3) will not be used in the subsequent work, but it is an important tool.

When we observe matter in motion with a velocity v, it appears to have more mass. Thus, something which to a man in the moving system appears to have a mass m_0 (called the rest mass) appears to us, past whom it is moving with a velocity v, to have a mass m given by

$$m = \frac{m_0}{\sqrt{1 - (v/c)^2}}. \tag{4}$$

The rest mass is the quantity of matter; it is what remains constant when we accelerate a body, while the relativistic mass m increases.

We are all familiar with the relativistic expression for energy E,

$$E = mc^2. \tag{5}$$

This is universally applicable. As a moving object has more mass than it would if it were standing still [according to (4)], (5) tells us that it will also have more energy. The additional energy is of course the kinetic energy of the body, that is, the energy associated with its motion.

In order to make calculations concerning space travel, we must associate with these laws of relativity two universal and basic laws of physics: the conservation of energy and the conservation of momentum. These laws say that the total energy and momentum must be the same before and after a physical event, such as the acceleration of a starship.

We can express the energy of the system in terms of its masses, at rest or moving, by means of relation (5). As the energy of each mass is proportional to the mass by the same constant, c^2, we see that the conservation of energy means the conservation of mass. *Rest mass* may be diminished, but if we use the energy produced to set matter in motion, the relativistic masses [as given by (4)] total the same as do the original masses. Or, electromagnetic radiation such as light may be produced, which, according to relativity, also has mass.

The momentum p of a material body of mass m and velocity v is

$$p = mv = \frac{m_0 v}{\sqrt{1 - (v/c)^2}}. \tag{6}$$

Momentum of course has a direction; this is the same direction as the velocity of the body.

According to relativity, electromagnetic radiation, including gamma rays, X rays, light and radio waves, must have mass and momentum as well as energy. Let us call the energy of a certain amount of radiation E_r, its mass m_r and its momentum p_r. The radiation travels with the velocity of light, c. The energy, mass and momentum are related by the following equations:

$$E_r = m_r c^2 \tag{7}$$

$$p_r = E_r/c = m_r c. \tag{8}$$

We see that (7) and (8) are really just the same as (5) and (6). However, radiation has no rest mass m_0.

We are now equipped with all the physical laws we ed for our calculations, except a quantum law governg radiation, which we will encounter in the next secon.

III. A "Clock Paradox"

In accord with the conservation of energy and the ct that energy is mc^2, when radiant energy such as ght appears, matter must disappear. Thus, when an om or molecule emits a quantum of light or other ectromagnetic radiation, such as radio waves or gama rays, it loses energy. Quantum mechanics tells us mething more about this process. The energy of a uantum of light or other radiation is Planck's conant h times the frequency of the light, f. Hence, from e conservation of energy,

$$hf = m_r c^2 = E_r \tag{9}$$

$$f = m_r c^2/h = E_r/h \tag{10}$$

$$h = 6.55 \times 10^{-34} \text{ joule/sec.} \tag{11}$$

ere m_r is the mass of the quantum of radiation and it is so equal to the mass lost by the atom or molecule in roducing the radiation. E_r is the energy of the radiaon.

Relativity tells us that the mass of each atom or molele *increases* when the atom or molecule is traveling ast. Further, our best clocks are regulated by the freuencies of radiation of ammonia molecules or cesium toms. If we took such a clock on a swiftly-moving pace ship, the mass of each molecule or atom would ncrease, and hence the small fraction of matter which would lose in emitting radiation would also have more ass. Thus, we might expect that the frequency of the lectromagnetic wave produced by the atom or molele would be higher than if the ship were standing still. ince this frequency governs the speed of our clocks, we ight expect the clocks on the ship to go faster by a actor $1/\sqrt{1-(v/c)^2}$.

Relativity tells us, quite to the contrary, that the ate of the moving clocks is decreased by a factor

$$S = \sqrt{1 - (v/c)^2}. \tag{1}$$

low are we to explain this seeming paradox?

Let us explore this matter warily. As a first step, let s assume that we send waves of light or other radiation rom earth to a moving space ship. What frequency ill these waves seem to have to an observer on the pace ship?

We will consider two cases, shown in Fig. 2. In (a), he ship is headed toward the waves of the radiation ith a velocity v, and of course the waves of radiation o toward the ship with the velocity c and of light. If λ the wavelength of the waves, that is, the distance beween wave crests, then the frequency f of the waves, hat is, the number of crests λ apart which will strike a xed object in a second, is clearly

$$f = c/\lambda. \tag{12}$$

However, we see the ship and the waves as having a relative velocity $c+v$, so we see the wave crests as striking the ship with a frequency f_1 given by

$$f_1 = \frac{c+v}{\lambda} = (1 + v/c)f. \tag{13}$$

Is this the frequency at which the man on the ship observes the wave crests to arrive? No, for his clock runs slow by a factor $\sqrt{1-(v/c)^2}$. Thus, to him the crests seem to arrive more rapidly, with a frequency f_d given by

$$f_d = \frac{f_1}{\sqrt{1 - (v/c)^2}}. \tag{14}$$

By using the value of f_1 given by (13) in (14) we find

$$f_d = \frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}} f. \tag{15}$$

This is known as the *relativistic Doppler frequency.*

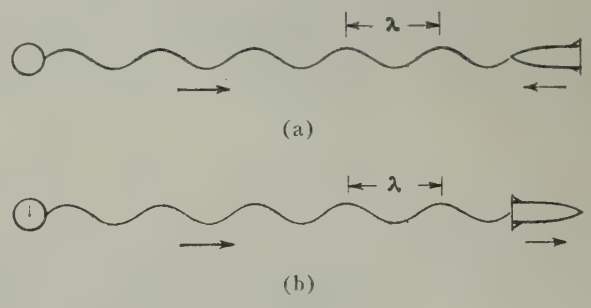

Fig. 2.

In the case shown in Fig. 2(b), in which the ship is going away from the source of radiation, we see the waves of radiation overtaking the ship with a relative velocity

$$c-v.$$

Accordingly, the frequency f with which *we* see crests strike the ship is

$$f_1 = (1 - v/c)f. \tag{16}$$

However, because the ship's clock runs slow, those on the ship observe a frequency

$$f_d = \frac{\sqrt{1 - v/c}}{\sqrt{1 + v/c}} f. \tag{17}$$

So far, we have stood still on earth and watched an observer on the moving ship measure the frequency of the radiation that we send him. But who is to say which is moving, the ship or the earth? Suppose that the captain of the ship watches an atom on the (to him) rapidly-moving earth emit radiation. The energy produced must be the change in relativistic mass, which is greater than the rest mass, times the square of the velocity of

light. Since the speed of the earth results in an increase in the mass, does this increase in mass directly account for the frequency of radiation emitted? No, it does not!

What we do know is that both energy and momentum must be conserved in the emission of radiation from the sources on earth. Let us assume that the radiation is emitted downward, at an angle θ with respect to the normal to the path of the earth, which travels to the right with a velocity v, as shown in Fig. 3.

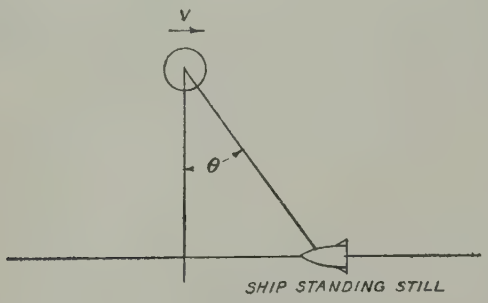

Fig. 3.

Let us consider the energy and momentum of an object traveling to the right with a velocity v which has x and y components v_x and v_y. The magnitude v of the velocity is

$$v = \sqrt{v_x^2 + v_y^2}. \tag{18}$$

The energy E will be

$$E = \frac{m_0 c^2}{\sqrt{1 - (v_x/c)^2 - (v_y/c)^2}}. \tag{19}$$

The x and y components of momentum, p_x and p_y, will be

$$p_x = \frac{m_0 v_x}{\sqrt{1 - (v_x/c)^2 - (v_y/c)^2}} \tag{20}$$

$$p_y = \frac{m_0 v_y}{\sqrt{1 - (v_x/c)^2 - (v_y/c)^2}}. \tag{21}$$

Let us suppose that the rest mass m_0 is changed by a small amount dm_0 and that the x and y components of velocity are changed by small amounts dv_x and dv_y. By differentiation, we find the changes in energy and momenta to be

$$dE = \frac{m_0(v_x dv_x + v_y dv_y)}{(1 - (v_x/c)^2 - (v_y/c)^2)^{3/2}} + \frac{c^2 dm_0}{\sqrt{1 - (v_x/c)^2 - (v_y/c)^2}} \tag{22}$$

$$dp_x = \frac{m_0(1 - (v_y/c)^2)dv_x}{(1 - (v_x/c)^2 - (v_y/c)^2)^{3/2}} + \frac{v_x dm_0}{\sqrt{1 - (v_x/c)^2 - (v_y/c)^2}} \tag{23}$$

$$dp_y = \frac{m_0(1 - (v_x/c)^2)dv_y}{(1 - (v_x/c)^2 - (v_y/c)^2)^{3/2}} + \frac{v_x dm_0}{\sqrt{1 - (v_x/c)^2 - (v_y/c)^2}}. \tag{24}$$

Let us now apply (22)–(24) to our case, in which the earth is whizzing by in the x direction with a velocity v. In this case

$$v_y = 0$$
$$v_x = v. \tag{25}$$

Accordingly,

$$dE = \frac{m_0 v dv_x}{(1 - (v/c)^2)^{3/2}} + \frac{c^2 dm_0}{\sqrt{1 - (v/c)^2}} \tag{26}$$

$$dp_x = \frac{m_0 dv_x}{(1 - (v/c)^2)^{3/2}} + \frac{v dm_0}{\sqrt{1 - (v/c)^2}} \tag{27}$$

$$dp_y = \frac{m_0 dv_y}{\sqrt{1 - (v/c)^2}}. \tag{28}$$

Now let E_r be the energy of the emitted radiation. The earth, in emitting the radiation, must lose an energy equal to the energy of the radiation, so that we must have

$$dE = -E_r. \tag{29}$$

Further, in order for momentum to be conserved, we must have

$$dp_x = -(E_r/c)\sin\theta \tag{30}$$

$$dp_y = (E_r/c)\cos\theta. \tag{31}$$

Let us further call the rest mass which a molecule or atom on earth loses in emitting radiation m_r. Thus

$$dm_0 = -m_r. \tag{32}$$

By substituting (29)–(32) into (26)–(28), we obtain

$$E_r = \frac{-m_0 v dv_x}{(1 - (v/c)^2)^{3/2}} + \frac{m_r c^2}{\sqrt{1 - (v/c)^2}} \tag{33}$$

$$(E_r/c)\sin\theta = \frac{-m_0 dv_x}{(1 - (v/c)^2)^{3/2}} + \frac{m_r v}{\sqrt{1 - (v/c)^2}} \tag{34}$$

$$(E_r/c)\cos\theta = \frac{m_0 dv_y}{\sqrt{1 - (v/c)^2}}. \tag{35}$$

We note that dv_y appears in (35) only. This equation can be regarded as giving dv_y directly in terms of E_r. We can eliminate dv_x by using (33) and (34); we obtain

$$E_r = \frac{\sqrt{1 - (v/c)^2}}{1 - (v/c)\sin\theta} m_r c^2. \tag{36}$$

Here $m_r c^2$ is the energy of a photon as seen from earth, while E_r is the energy of the photon according to an observer who says that the earth is moving past him with a velocity v, as shown in Fig. 3. As frequency is

roportional to energy, then if f is the frequency of a hoton as observed on earth and f_d as observed by our fixed" observer, (36) tells us that

$$f_d = \frac{\sqrt{1-(v/c)^2}}{1-(v/c)\sin\theta} f. \tag{37}$$

When $\theta = \pi/2$, so that $\sin\theta = 1$, we have the case of arth and ship approaching, to which (15) applies, and e are gratified to see that (37) indeed reduces to (15). When $\theta = -\pi/2$, so that $\sin\theta = -1$, we have the case f earth and ship separating, and indeed, (37) reduces o (17), which applies to this case.

When $\theta = 0$, so that $\sin\theta = 0$, the earth is neither approaching nor receding from the ship. Here we observe he oscillator frequency of the ship, unaffected by relative motion; we see from (37) that it is

$$\sqrt{1-(v/c)^2} f. \tag{38}$$

This is exactly in accord with the shrinking factor S of 1).

At first thought, it may seem puzzling that while the elativistic mass of the matter lost during radiation of he quantum is $m_r/\sqrt{1-(v/c)^2}$, the mass of the radiation roduced is only $m_r\sqrt{1-(v/c)^2}$. We note, however, that or momentum to be conserved in the x direction after he earth has lost rest mass, the earth must travel faster, nd this means that the rest of the earth must gain nergy during the process of radiation.

We may also note that radiation which to the fixed bserver appears to be traveling normal to the x axis must appear to an observer on the "moving" earth to have a component of motion in the $-x$ direction. In illustration, we may note that a swiftly flying airplane would have to eject a bomb violently backward in order for it to fall straight down to a man on earth.

IV. The Clock Paradox

We have just considered *a* clock paradox. This is not, however, *the* clock paradox that most people mean when they use the words. In the clock paradox, one of two identical twins goes off in a starship at 99.5 per cent of the speed of light. As observed from earth, his clock runs only 1/10 normal speed. After five years pass on earth, the ship turns around, and 10 years from takeoff he lands on earth. The twin steps out, but he has aged only 1 year, while his brother who stayed on earth is 10 years older than when the ship started.

However, it has been argued that to the twin on the ship, the clock on earth should have appeared to be running at 1/10 normal speed. Should we say that the twin on earth ages only one year while the twin on the ship ages 10 years?

Such arguments are confusing because they involve one in considerations of the time on distant earth when the ship turns around, or the time on the ship as reckoned from earth when the ship turns around. As we have seen, what events (perhaps clock readings) we take to be simultaneous depend on velocity.

We can avoid a lot of trouble if we make only such time comparisons as involve objects at the same point. Among such objects we may include electromagnetic waves emitted by the ship or by the earth as well as material objects.

How do we measure the clock rate on some object in motion with respect to ourselves, anyway? We can infer this rate from the relativistic Doppler frequency. Let us, however, work with this directly and see what sort of answers the approach leads us to.

First, let us consider the starship from the point of view of earth people. As indicated in Fig. 4, the ship goes out at a velocity v toward some point * (perhaps a star). It then turns around and returns at the same velocity v. The point * is at a distance L from earth as measured by earthmen.

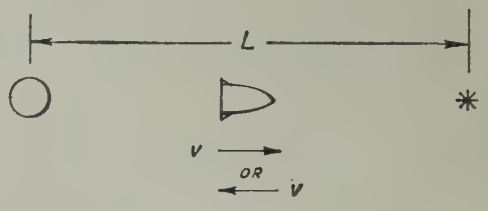

Fig. 4.

Suppose that the ship carries a standard oscillator just like one left on earth. Each oscillator would oscillate with the same frequency f if it were standing still. Now, let us measure elasped time in terms of cycles of oscillation of these oscillators. On earth, the time t_e in seconds between the departure and the arrival of the starship will be

$$t_e = \frac{2L}{v}. \tag{39}$$

The number of cycles of oscillation N_e of the earth clock is thus

$$N_e = ft_e = \frac{2Lf}{v} \tag{40}$$

What about radiation received from the ship? On the outward journey, when the ship is going away from earth, the Doppler frequency f_{d1} received at earth will be less than f; in fact, (17) says that it will be

$$f_{d1} = \frac{\sqrt{1-v/c}}{\sqrt{1+v/c}} f. \tag{41}$$

But, radiation of this frequency is emitted from the ship right up to the time it turns around, when it is a distance L from the earth. The last of this radiation, which travels toward earth with a velocity c, will reach earth at a time L/c later than the time at which the ship turns

around. Hence, the radiation received on earth has the frequency f_{d1} for a time

$$L/v + L/c \tag{42}$$

out of the total time of the journey, $2L/v$. For the rest of the time, which must be

$$2L/v - (L/v + L/c) = L/v - L/c, \tag{43}$$

the Doppler frequency received will be that for a source approaching the earth, as given by (15); we will call this frequency f_{d2}.

$$f_{d2} = \frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}} f. \tag{44}$$

To get the total number of cycles of radiation N_s which have been produced on the ship and have struck the earth between the time the ship left and the time it returned, we should multiply the time (42) by the frequency (41) and add the product of the time (43) and the frequency (44). Thus

$$N_s = \frac{Lf}{v}\left[(1 + v/c)\frac{\sqrt{1 - v/c}}{\sqrt{1 + v/c}} + (1 - v/c)\frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}}\right]$$

$$N_s = \frac{2Lf}{v}\sqrt{1 - (v/c)^2}. \tag{45}$$

We see by comparing (40) and (45) that according to this calculation, the oscillator on the ship must have run slower than the oscillator on earth by just the proper relativistic time shrinking factor, S of (1).

But, suppose that we are on the ship? Here the picture is as shown in Fig. 5. The universe is whizzing by in one direction or the other with a velocity v. Because of this, the distance between earth and * has shrunk relativistically to a distance

$$L\sqrt{1 - (v/c)^2}. \tag{46}$$

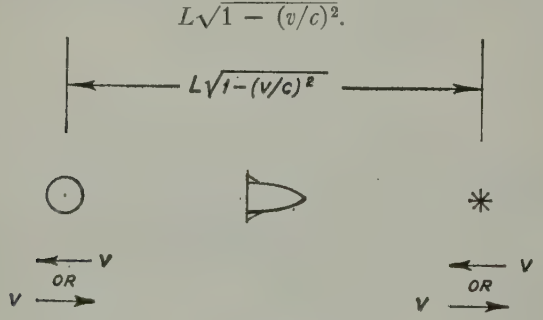

Fig. 5.

Accordingly, on the ship the "trip" from earth to * and back takes a time t_s

$$t_s = \frac{2L\sqrt{1 - (v/c)^2}}{v}. \tag{47}$$

The number of cycles N_s emitted by the ship's oscillator in this time is

$$N_s = ft_s = \frac{2Lf\sqrt{1 - (v/c)^2}}{v}. \tag{48}$$

What about the radiation from earth? On the "journey out" the earth will appear to be moving away from us with a velocity v for a time half that of (47), which is the time for the two-way trip. But, when we reach * we change our motion with respect not only to the earth and the star, but with respect to the radiation from the earth as well. The waves of radiation which we immediately encounter are already in space; we rush to meet them, and the observed frequency immediately changes from that of (17) to that of (15). Hence, we have the lower and the higher Doppler frequencies each for the same time. Thus, the total number of cycles N_e which leave earth and fall on the ship during both parts of the trip is

$$N_e = \frac{Lf\sqrt{1 - (v/c)^2}}{v}\left[\frac{\sqrt{1 - v/c}}{\sqrt{1 + v/c}} + \frac{\sqrt{1 + v/c}}{\sqrt{1 - v/c}}\right]$$

$$N_e = \frac{2Lf}{v}. \tag{49}$$

Let us now compare the calculations made by the earthbound observer with those made by the observer on the ship. The results are exactly the same. N_s from (45) is exactly N_s from (48), and N_e from (40) is exactly N_e from (49). If we work matters out carefully, there is no clock paradox involved. The crew on the starship age less rapidly than those left behind on earth.

It may of course be objected that the acceleration of turning does dire things to the ship's clock. Here we can at least say that the effect should be the same for a long as for a short trip, and could only be additive.

The reader can easily arrive at the above result in another simple way. Assume two ships, the first going from the earth to * with a velocity v and the second going from * to the earth with a velocity v. Assume that the ships pass one another at *. Assume that ship 1 and earth set their clocks to zero as ship 1 passes earth. Imagine that ship 2 sets its clock by the clock of ship 1 as ship 2 passes ship 1. Let earth and ship 2 compare clocks as ship 2 passes earth. It will be found that the reading of the clock of ship 2 (which represents elasped time of ship 1 from earth to star plus elapsed time of ship 2 from star to earth) is smaller than the reading of the earth clock by the factor $\sqrt{1-(v/c)^2}$, no matter what frame of reference we use.

V. Frequencies on a Ship with a Changing Velocity

Consider the moving space ship shown in Fig. 6. Here the acceleration a is upward. In a, at time t, the ship of length L is moving downward with a velocity v. In b, a time L/c later, the ship is stationary and the observer at the tail-end of the ship is right next to our stationary observer O. Let us assume that the relativistic Doppler shift accounts for the frequencies observed, and explore the consequences.

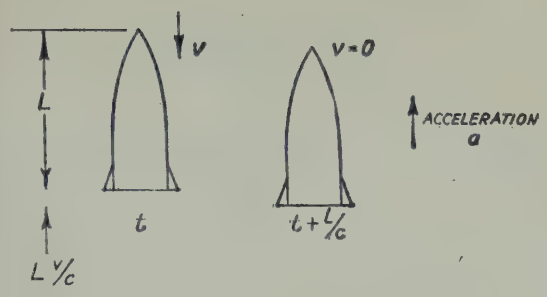

Fig. 6.

As we are dealing with moderate accelerations and velocities, we will assume Newtonian laws of motion. Further, we can at an appropriate point neglect Lv/c in comparison with L.

The radiation that the stationary observer, and the other stationary observer on the tail of the ship, see at time $t+L/c$ left the nose a time very nearly L/c earlier, when the ship was traveling downward with a velocity v. Hence, the observed relativistic Doppler frequency for this radiation will be

$$f_d = f\frac{\sqrt{1+v/c}}{\sqrt{1-v/c}} \doteq f(1+v/c). \tag{50}$$

Thus, the stationary observer and the observer in the tail of the ship find radiation as if from a clock running faster by a fraction $\Delta f/f$

$$\Delta f/f = v/c. \tag{51}$$

Now, assuming Newtonian acceleration, very nearly

$$v = a \qquad t = aL/c. \tag{52}$$

When we substitute v from (52) in (51) we obtain

$$\Delta f/f = aL/c^2. \tag{53}$$

Einstein's principle of equivalence asserts that a field due to acceleration is indistinguishable from a gravitational field. A man cooped up in the space ship thus has no way of knowing that the ship is changing velocity. He may think of it as sitting on the ground and experiencing a gravitational field of acceleration a. Hence, we conclude that a clock at height L in a gravitational field of acceleration a runs faster than a clock on the ground by a fraction given by (53).

This is a well-known relativistic clock effect which predicts a red shift in radiation from a massive body such as the sun.

We can deduce this effect in another way. If a mass m is lifted to a height L against a field of acceleration a, it gains an energy maL and this is a gain of a fraction aL/c^2 of the total energy mc^2. Thus if a fraction of the mass is converted to photons which return to the ground a distance L below, these photons must have an energy greater by this same fraction aL/c^2 than if they had been emitted before the mass was raised. As frequency is proportional to energy, the frequency of the photons from the source at a height L will be raised by just the fraction given by (53).

In connection with the "clock paradox" of Section IV, it has been objected by some that "relativity" requires that the same time elapse for the traveler as for stay-at-homes, but this is not so.

Special relativity can deal only with relative time rates ascribable to velocity differences, not with those caused by gravitational fields or accelerations. In Section IV we scrupulously took relative velocities into account. We insisted, however, that the ship change its velocity with respect to earth, star and the radiation as well. We did this because the rockets applied a force to the ship, but not to the earth, the stars and the radiation.

The ship captain might insist, however, that during acceleration his ship is being supported in a gravitational field, while all the heavens fall past it. In this case he would have to take into account the effect of this gravitational field in increasing the frequency of the radiation traveling toward him between his ship and earth. No doubt the complete and general relativist could do not only this, he could also treat a case of protracted acceleration and deceleration. It seems simplest, however, to proceed as in Section IV, and other results must be consistent with the results obtained there.

VI. Clock Rate on a Satellite

Let us imagine a very accurate oscillator on a satellite in a circular orbit at radius r. According to Newton's laws, the orbital velocity is given by

$$v^2 = gr(r_0/r)^2. \tag{54}$$

Here r_0 is the radius of the earth and g is the acceleration of gravity at the surface. Accordingly, there is a fractional *reduction* in clock rate as observed from the earth of

$$1 - \sqrt{1-(v/c)^2} \doteq (1/2)gr_0(r_0/r)/c^2. \tag{55}$$

The potential energy of a unit mass at radius r with respect to the surface (at r_0) is

$$g(r_0/r)(r-r_0). \tag{56}$$

In accordance with Section V, there is a fractional *increase* in clock rate because of the gravitation field of

$$g(r_0/r)(r-r_0)/c^2. \tag{57}$$

Thus, the net fractional change of clock rate, $\Delta f/f$, is

$$\frac{\Delta f}{f} = \frac{g}{c^2}\frac{r_0}{r}\left(r - \frac{3}{2}r_0\right). \tag{58}$$

We must note that this will be the frequency when the satellite is directly overhead; a Doppler shift will be present when the satellite is approaching or receding, in accordance with (37) (overhead corresponds to $\theta = 0$).

If the gravitational "red shift" were not taken into account, the frequency decrease at a radius of 6000

miles (a height of 2000 miles) would be about 4 parts in 10^{10}. When the red shift is taken into account the net frequency change at this altitude is, according to (58), zero.

We should note that in making calculations of this sort, in accord with Section V, we take into account velocities and gravitational fields in the observer's frame of reference. Fields experienced by someone else, as, for instance, a force felt in the satellite because of an acceleration of the satellite, are irrelevant.

VII. The Photon Rocket

Can we ever hope to travel with anything like the speed of light? For this purpose, some invoke the photon rocket. Of the total rest mass m_0 of the rocket we regard all but a fraction a (or a rest mass am_0) as fuel. We will not burn this fuel, nor fission it, nor fuse it. We will turn it all completely into radiation and use the pressure of this radiation to thrust the ship forward.

Of course we don't know how to turn matter completely into radiation. If we could do this, and if the minutest fraction of the radiation released heated the ship rather than pushing it forward, it would of course fry the crew. We will, however, assume that all the energy goes into pushing the ship, and none into heating it.

Before the ship sets off on its journey, it has zero velocity with respect to earth, a mass m_0 and a total energy m_0c^2. The ship shoots out radiation of total energy E_r to the left and itself shoots off to the right, attaining a velocity v. Its remaining rest mass is now am_0 and its relativistic mass is

$$\frac{am_0}{\sqrt{1-(v/c)^2}}. \tag{59}$$

According to the conservation of energy, the energy of the radiation produced, E_r, plus the final energy of the ship must be equal to the initial energy of the ship, m_0c^2

$$E_r + \frac{am_0c^2}{\sqrt{1-(v/c)^2}} = m_0c^2. \tag{60}$$

According to the conservation of momentum, the momentum of the radiation (directed to the left) must equal the momentum attained by the ship (directed to the right), or

$$E_r/c = \frac{am_0v}{\sqrt{1-(v/c)^2}}. \tag{61}$$

From (60) and (61) we obtain

$$v/c = \frac{1-a^2}{1+a^2}. \tag{62}$$

Now, we remember that to make time pass only a tenth as fast on the ship as on the earth, we must attain 99.5 per cent of the speed of light; that is, v/c must be 0.995. If we use a photon rocket to attain this speed, what fraction of the initial mass or matter will we have left?

The answer turns out to be a fraction

$$a = 0.05. \tag{63}$$

This sounds extreme, but think of the trip out and back! We start out with a mass m_0. After getting up to 99.5 per cent of the speed of light we have left of the ship only a rest mass of 0.05 m_0. After stopping at the far end, we have only a mass (0.05) (0.05) m_0, or 0.0025 m_0. After starting back and then stopping at earth, we are left with only a fraction 0.00000625 of our original mass, which sounds rather impractical.

Did we do the wrong thing? Instead of using up rest mass to shoot radiation off to the left, we might have used it to shoot a part of the ship off to the left with a velocity v_1 and a relativistic mass m_1, while the ship proper, which retains a fraction a of the total original rest mass m_0, goes off to the right with a velocity v. Remember, m_1 is *relativistic* mass and am_0 is *rest mass*. With this in mind, the conservation of energy becomes

$$m_1c^2 + \frac{am_0c^2}{\sqrt{1-(v/c)^2}} = m_0c^2. \tag{64}$$

The conservation of momentum is

$$m_1v_1 = \frac{am_0v}{\sqrt{1-(v/c)^2}}. \tag{65}$$

From these equations we obtain

$$v/c = \sqrt{1-a^2(1+v/v_1)^2}. \tag{66}$$

We are of course interested in the case in which the fraction a is very small and v/c is very near to unity. In this case, unless the mass shot out to the left is very much greater than the remaining mass of the ship which moves to the right, v_1/c will be very nearly unity too. In other words, v/v_1 will be nearly equal to one. If this is true and is a is small, then (66) is approximately

$$v/c = 1 - 2a^2. \tag{67}$$

Under the same circumstances, according to (62) the photon rocket gives us a speed of approximately

$$v/c = 1 - 2a^2. \tag{68}$$

We see that (67) and (68) are the same. The remaining fraction a of the initial rest mass attains the same speed whether we turn all of the rest of the mass into photons and use these to accelerate the rest mass am_0, or whether we use some of the mass to shoot a part of the mass of the ship rearwards with a speed close to the speed of light.

We could do a little better if we could use the energy released to accelerate the ship by pushing against some fixed or very massive body—the universe, for instance. In this case all the energy will appear in the ship, and the conservation of energy will lead directly to the velocity, giving

$$\frac{am_0c^2}{\sqrt{1-(v/c)^2}} = m_0c^2$$

$$v/c = \sqrt{1-a^2} \tag{69}$$

When a is very small, very nearly

$$v/c = 1 - a^2/2. \tag{70}$$

We see that this is somewhat better than the other two cases [see (67) and (68)]. It is still not good enough to allow us to make a trip with nearly the speed of light. Moreover, I can't think of a plausible way to do it, except perhaps in taking off from a planet.

How is it that we find it possible on earth to accelerate electrons and protons far closer to the speed of light? The answer is, that we do have a massive body to push against, and besides this we do not rely on the energy of the particles, but instead have a huge fixed power plant; it is with these that we accelerate measly little atomic particles to speeds near that of light. With a sort of fixed space cannon and a huge mass-conversion power source we might shoot a space ship from earth with 99.5 per cent of the speed of light, but it seems unlikely that the crew would survive the acceleration.

VIII. Fuel from Space

Space is full, loosely speaking, of matter, which is mostly hydrogen. It is said that on the average there is about one atom of hydrogen per cubic centimeter, but to be on the safe side let us assume some larger number M of hydrogen atoms per cubic centimeter, or $M\times10^6$ atoms per cubic meter. As the mass of a hydrogen atom is

$$1.66 \times 10^{-27} \text{ kilograms} \tag{71}$$

the mass of hydrogen per cubic meter is

$$1.66 \times 10^{-21} M \text{ kilograms.} \tag{72}$$

Let us assume a space ship of mass m_0 kilograms which, in literally tunneling through space, sweeps up all the matter over an area A, turns it into radiation, and uses the radiation to push the ship forward. In a distance L the ship has acquired and used a mass which we shall call m_i of interstellar matter; m_i will be given by

$$m_i = 1.66 \times 10^{-21} maL \text{ kilograms.} \tag{73}$$

If v is the final velocity attained by the ship of rest mass m_0 and E_r is the energy of the radiation produced, the conservation of energy tells us that

$$E_r + \frac{m_0c^2}{\sqrt{1-(v/c)^2}} = (m_i + m_0)c^2. \tag{74}$$

Initially, there is no radiation and neither the interstellar matter nor the ship has any momentum. Finally, in the tunnel behind the ship there is no interstellar matter (we used it up), there is radiation with momentum to the left, and the ship has a momentum to the right. The conservation of momentum tells us

$$E_r/c = \frac{m_0v}{\sqrt{1-(v/c)^2}}. \tag{75}$$

From (74) and (75), we obtain

$$v/c = \frac{(1 + m_i/m_0)^2 - 1}{(1 + m_i/m_0)^2 + 1}. \tag{76}$$

From (73) we easily see that if the distance of travel, L, is zero, m_i is zero, and thus (76) tells us that we are at a standstill.

How fast are we going after a ten-light-year trip? A light year is

$$\text{one light year} = 9.48 \times 10^{15} \text{ meters.} \tag{77}$$

Let us assume a generous scoop (made of force fields, no doubt) which is 100 meters square, so that

$$A = 10^4 \text{ square meters.} \tag{78}$$

We thus see that the mass of interstellar matter collected will be

$$m_i = (1.66 \times 10^{-21})(10^4)(10)(9.48 \times 10^{15})M$$

$$m_i = 1.57\ M \text{ kilograms.} \tag{79}$$

Surely, a habitable starship will weigh several thousand kilograms. Let us assume the mass of the ship to be 15,700 kilograms (about 17.5 tons). Let us generously assume not one but 1000 hydrogen atoms per cubic centimeter. This makes

$$m_i/m_0 = \frac{(1.57)(1000)}{(15{,}700)} = 0.1. \tag{80}$$

From (80) and (76), we obtain

$$v/c = 0.093. \tag{81}$$

Clearly, it is impossible to attain a velocity close to that of light by using interstellar matter as fuel.

A Maser Amplifier for Radio Astronomy at X-Band*

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Summary—**The design and operating characteristics of a maser radiometer for use in radio astronomy at 3-cm wavelength are discussed. The operating system which is described has a bandwidth of 5.5 mc and an input noise temperature, including background radiation into the antenna, of about 85°K. An rms fluctuation level of about 0.04°K is attained using an averaging time of 5 seconds. A discussion of the factors determining the sensitivity of such devices is presented.**

Introduction

THE low noise anticipated for maser amplifiers at the inception of maser techniques has by now received considerable experimental verification.[1] On the theoretical side, a lower limit to the effective input noise temperature[2] arising from spontaneous emission has been set at $h\nu/k = 0.048\nu$°K for a two-level maser (or a three-level maser in the absence of noise associated with the pumping source), amplifying at a frequency ν expressed in kmc. Experimental measurements of the noise figure of two- and three-level masers have been hampered by the presence of thermal noise from circuit components considerably in excess of the limiting noise. However, a value of close to 2°K has been set experimentally for the contribution of the amplification process in some maser devices.[3]

Realization of an amplification technique with such low inherent noise and the availability of a suitable three-level maser medium in ruby[4] has made possible the development of an operational radiometer whose sensitivity is largely limited by the purely thermal radiation from components preceding the amplifier and from antenna spillover.

The radiometer to be described has been in use in the study of continuum radiation from the planets and other discrete radio sources with the U. S. Naval Research Laboratory 50-foot reflector since April, 1958. An effective system noise temperature of the order of 85°K has been attained, of which about 20°K is due to noise entering the antenna from external sources. The remaining noise of 65°K corresponds to a noise figure of $1+65/290=1.2$. An improvement in sensitivity for detection of thermal radiation of a factor of about 12 was obtained over a superheterodyne receiver with a noise figure of 9.8 db[5] and an IF bandwidth of 5.5 mc. The latter receiver, of course, accepted signal energy in both image bands. This system should be regarded only as a first approximation to what may be achieved by use of masers. Nevertheless its noise figure is notably better than that of previous radiometers, and a description of its characteristics will perhaps be of value for future and more finished system design.

The 5.5-mc bandwidth was obtained using a maser with voltage gain bandwidth product of ~50 mc. A gain bandwidth product of ~100 mc was available from the same maser under laboratory conditions of optimum magnetic field homogeneity.

Improvement in Sensitivity with a Maser Preamplifier

The radiometer was a modified Dicke-type system[6] in which the receiver consisted of a ruby maser preamplifier followed by a superheterodyne receiver. We wish to estimate the sensitivity of such a radiometer in terms of the maser and receiver parameters.

Let

T_1°K = operating noise temperature at the input of the maser, including contributions from the following noise sources:

a) Radiation from lossy ferrite switch and circulator preceding the maser.
b) Waveguide losses between the input horn and the maser cavity.
c) Radiation from cavity walls at the temperature of the cooling bath.
d) Spontaneous emission in ruby.
e) Ground pickup through antenna spillover..
f) Thermal radiation from atmospheric absorption.

T_2°K = equivalent temperature of the receiver input, equal to $(F-2)290$°K including mixer noise, IF amplifier noise, and mixer conversion loss.

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[1] J. P. Gordon and L. D. White, "Noise in maser amplifiers—theory and experiment," PROC. IRE, vol. 46, pp. 1588–1594; September, 1958. References to the published theoretical and experimental work on maser noise figures are given in this paper.

[2] The term "effective input noise temperature" is used according to the definition in the reference above and is equal to $(F-1)$ 290°K. In a paper by L. E. Alsop, J. A. Giordmaine, C. H. Townes, and T. C. Wang, "Measurement of noise in a maser amplifier," *Phys. Rev.*, vol. 107, pp. 1450–1451, September 1, 1957, the term "noise figure" was used for the quantity $(F-1)$, leading to the quotation of maser noise figures less than unity. The reference temperature was taken as 300°K. In this paper the term noise figure and the symbol F are used in accordance with the accepted definition. See H. T. Friis, "Noise figures of radio receivers," PROC. IRE, vol. 32, pp. 419–422; July, 1944.

[3] A. C. McWhorter and F. R. Arams, "System-noise measurement of a solid state maser," PROC. IRE, vol. 46, pp. 913–914; May, 1958.

[4] G. Makhov, C. Kikuchi, J. Lambe, and R. W. Terhune, "Maser action in ruby," *Phys. Rev.*, vol. 109, pp. 1399–1400; February 15, 1958.

[5] The noise figure of 9.8 db corresponds to an effective input noise temperature of $(F-2)290=2190$°K at the input to the 5.5-mc bandpass. This is just twice the noise figure measured by use of a broadband no se source substituted for the antenna horn. It is expressed in this form for easy comparison with a single-sideband receiver.

[6] R. H. Dicke, "Measurement of thermal radiation at microwave frequencies," *Rev. Sci. Instr.*, vol. 17, pp. 268–275; July, 1946.

b = maser voltage gain-bandwidth product, expressed in mc.
$\Delta\nu_1$ = maser bandwidth at half power, expressed in mc.
$\Delta\nu_2$ = IF bandwidth at half power, expressed in mc.
$\Delta\nu_0$ = bandwidth of filter following lock-in detector, expressed in mc.

In the absence of the maser preamplifier, the superheterodyne receiver accepts continuum signal power from both the signal band and the image band, *i.e.*, $2\Delta\nu_2$, the only input preselection occurring in the mixer crystals. The 30 cps half-wave lock-in detector is preceded by a narrow band audio filter. For square-switching and demodulation waveshapes, the rms fluctuation level at the receiver output, expressed in terms of antenna temperature, is given[6,7] approximately by

$$\Delta T = \sqrt{2}T_2\left(\frac{\Delta\nu_0}{\Delta\nu_2}\right)^{1/2}. \tag{1}$$

It is assumed that the IF response is constant over $\Delta\nu_2$ and otherwise zero, and that $\Delta\nu_0 \ll \nu_0 \ll \Delta\nu_2$, where ν_0 is the switching frequency. The output filter frequency response is somewhat complicated but may be approximated by a bandwidth $\Delta\nu_0 = 1/4\tau$, where τ is a response time of 5 seconds. Eq. (1) becomes

$$\Delta T = \frac{T_2}{(2\tau\nu_2)^{1/2}}. \tag{2}$$

For a noise figure of 9.8 db, $T_2 = 2190°\text{K}$. Taking $\tau = 5$ seconds and $\Delta\nu_2 = 5.5$ mc, we obtain from (2) $\Delta T = 0.3°\text{K}$. The disagreement between this temperature fluctuation and the observed value of 0.5°K is attributed to appreciable distortion of the assumed square wave modulation waveshape and to use of half-wave lock-in detection with an audio filter which did not completely reject harmonics of the switching frequency.

In the presence of the maser preamplifier, the noise temperature T_2 referred to the input of the system is

$$T_2^* = \frac{T_2}{2 + \dfrac{(G-1)\Delta\nu_1}{\Delta\nu_2}} \tag{3}$$

where it is assumed for simplicity that the maser has uniform power gain G over the bandwidth $\Delta\nu_1$ within the receiver signal band, and unity gain elsewhere including the image band. In this notation, $b = \sqrt{G}\Delta\nu_1$ and as may be seen from (23) b is approximately independent of G for a given maser design. It is noted that in the extreme case of $G = 1$, *i.e.*, of the maser removed from the system, $T_2^* = T_2/2$ since both the signal and image bands are receptive. Where the maser has useful gain and bandwidth, the effective receiver bandwidth approaches $\Delta\nu_1$ and from (2) we obtain

$$\Delta T = \left(\frac{2}{\tau}\right)^{1/2}\left[\frac{T_1}{(\Delta\nu_1)^{1/2}} + \frac{T_2^*}{(\Delta\nu_2)^{1/2}}\right]. \tag{4}$$

For the useful case of $G \gg 1$ and $G\Delta\nu_1 \gg 2\Delta\nu_2$

$$\Delta T = \left(\frac{2}{\tau\Delta\nu_1}\right)^{1/2}\left[T_1 + \frac{T_2}{G_1}\left(\frac{\Delta\nu_2}{\Delta\nu_1}\right)^{1/2}\right]. \tag{5}$$

Where the available gain bandwidth b of the maser is small, *i.e.*,

$$b < \sqrt{\frac{2T_2}{T_1}}\,\Delta\nu_2,$$

the fluctuation level (5) can be minimized by adjusting the gain of the maser to an optimum value

$$G = \left[2\,\frac{T_2}{T_1}\left(\frac{\Delta\nu_2}{b}\right)^{1/2}\right]^{4/3}. \tag{6}$$

With optimum gain,

$$\Delta T = \frac{3}{(2\tau)^{1/2}}\left[\frac{2T_2T_1^2(\Delta\nu_2)^{1/2}}{b^2}\right]^{1/3}. \tag{7}$$

For a larger gain-bandwidth product,

$$b > \sqrt{\frac{2T_2}{T_1}}\,\Delta\nu_2,$$

the optimum gain is just the gain for which the maser bandwidth is equal to the receiver bandwidth. In this case

$$\Delta T = \left(\frac{2}{\tau\Delta\nu_2}\right)^{1/2}\left(T_1 + \frac{T_2}{G}\right)$$
$$= \left(\frac{2}{\tau\Delta\nu_2}\right)^{1/2}\left[T_1 + \frac{T_2(\Delta\nu_2)^2}{b^2}\right]. \tag{8}$$

The limiting sensitivity for

$$b \gg \sqrt{\frac{T_2}{T_1}}\,\Delta\nu_2$$

is

$$\Delta T = \left(\frac{2}{\tau\Delta\nu_2}\right)^{1/2}T_1. \tag{9}$$

In this case the effective system input noise temperature is just the input temperature to the maser.

Now the bandwidth of a microwave superheterodyne receiver can be varied considerably without a large modification in noise figure. As a corollary of (8) and (9), the optimum receiver bandwidth for use with a maser preamplifier of gain bandwidth product b is

$$(\Delta\nu_2)_{\text{opt}} = b\sqrt{\frac{T_1}{3T_2}}. \tag{10}$$

Assuming that the optimum receiver bandwidth can be used, and that the gain of the maser has been opti-

[7] W. Selove, "A dc comparison radiometer," *Rev. Sci. Instr.*, vol. 25, pp. 120–122; February, 1954.

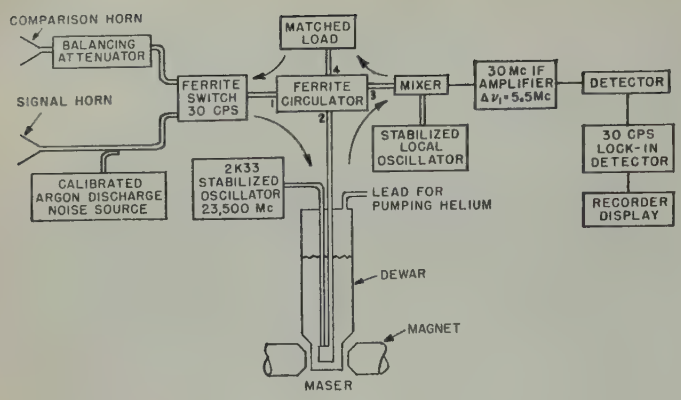


Fig. 1—Schematic diagram of the maser radiometer. The components, with the exceptions of the lock-in amplifier and the recorder display, were mounted at the focus of the reflector.

mized, the minimum fluctuation level obtainable with a maser of gain bandwidth product b is given by

$$\Delta T = \frac{3.6}{\sqrt{2b\tau}} T_1 \left(\frac{T_2}{T_1}\right)^{1/4}. \tag{11}$$

In the maser radiometer to be described, pertinent parameters for the superheterodyne receiver are given by Table I. The minimum observed fluctuation level was about 0.04°K. This result represents an improvement of a factor of approximately 12 in sensitivity over the radiometer without the maser preamplifier.

TABLE I

Characteristics of Superheterodyne Receiver

$T_2=2190$°K (noise figure 9.8 db)
$\Delta\nu_2=5.5$ mc
$\tau=5$ seconds

The contributions to the input noise temperature T_1 are listed below. The contribution from antenna spillover is an estimate based on absolute gain measurements in the forward direction, and an assumed pattern in the backward direction.

a) Ferrite switch (antenna-comparison horn), 0.2-db forward loss, 13°.
b) External waveguide losses (2 feet of RG 52/U and associated flanges), 10°.
c) Ferrite circulator, 0.1-db forward loss, 7°.
d) Atmospheric absorption (antenna elevation 45°),[8] 6°.
e) Spontaneous emission, 3°.
f) Cavity walls (bath temperature 1.4°K), <0.5°.
g) Antenna spillover, 20°.

The contribution of receiver noise to the input temperature is $T_2^*=T_2/G=26$°K, giving a total input noise temperature of approximately 86°K. The predicted fluctuation level (8) is 0.02°K, in reasonable agreement with the observed value of 0.04°K. The difference between predicted and observed fluctuations may come primarily, as in the case of the radiometer without a maser, from inaccurate assumptions about the modulation shape and characteristics of the coherent detection.

[8] D. C. Hogg, *J. Appl. Phys.*, to be published.

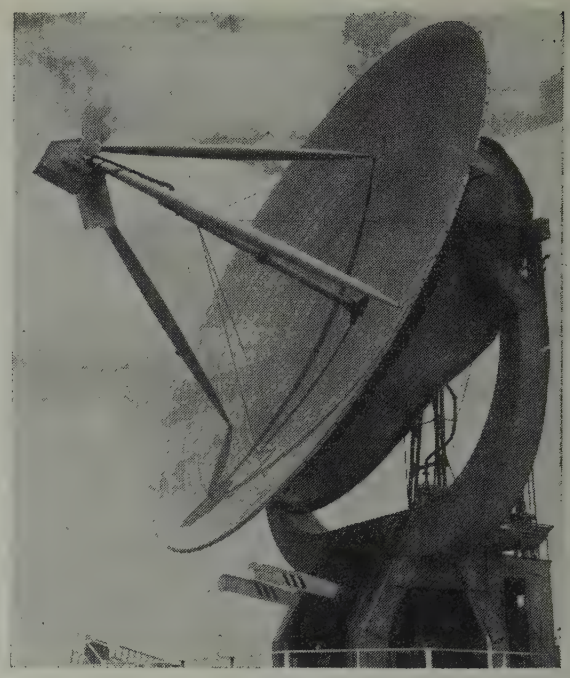


Fig. 2—The radiometer mounted near the focus of the NRL 50-foot reflector.

With an available voltage-gain bandwidth product of 50 mc, the optimum receiver bandwidth in the presence of 2190°K receiver input temperature is 4.7 mc [cf. (13)]. The actual receiver bandwidth of 5.5 mc was thus almost the optimum bandwidth.

Apparatus: General Description

The radiometer is shown schematically in Fig. 1. The maser, the local oscillator, and the IF amplifier were mounted adjoining the focus of the 50-foot reflector.[9] The over-all mounting is indicated in Fig. 2, in which the radiometer is shown encased in a protective covering. The vacuum pump for maintaining helium pressure at 1 to 2 mm was mounted behind the reflector. In Fig. 3 the equipment at the focus is shown.

The apparatus was modified Dicke system[10] in which a ferrite circulator was used to switch alternately between the 50-foot antenna and a comparison horn pointed at the sky. A four-port circulator was used to isolate the maser from receiver radiation. The second detector output was synchronously detected in a half-wave lock-in detector, with the reference voltage the same square-wave voltage used to drive the ferrite switch. The output of the lock-in detector was displayed on a recorder.

Preparation of the system for observing was carried

[9] The attenuation in the length of RG52/U waveguide necessary to connect the feed horn to a maser amplifier at the base of the antenna would have introduced an additional 150°K to the input noise temperature.

[10] C. H. Mayer, T. P. McCullough, and R. M. Sloanaker, "Measurements of planetary radiation at centimeter wavelengths," Proc. IRE, vol. 46, pp. 260–266; January, 1958.

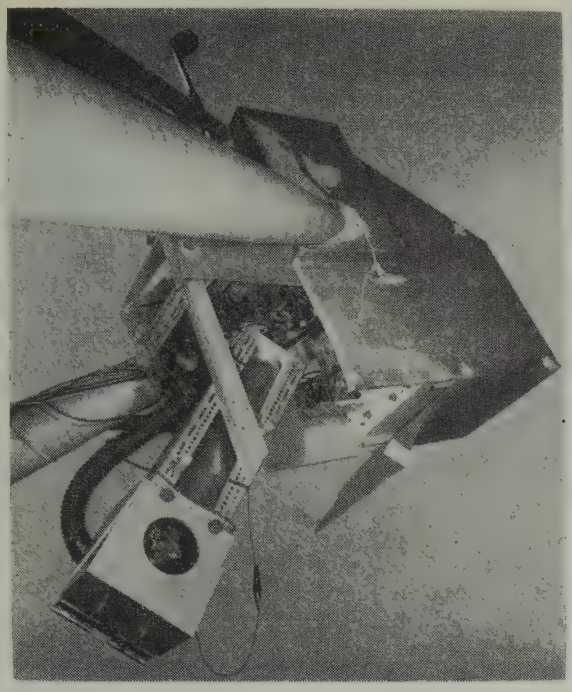


Fig. 3—View of the assembly mounted near the focus.

out on the ground by precooling the dewar containing the maser cavity and input waveguide by filling the outer portion of the dewar with liquid nitrogen and the inner dewar with liquid helium. The dewar is mounted at the focus, and the necessary waveguide connections are made. The helium capacity of the dewar allowed for 12 to 15 hours of continuous operation at 1.4°K.

Although not continuously variable, the operating frequency could be adjusted by moving the ruby about slightly in the cavity or by variation in a small amount of dielectric material also inserted in the cavity. The system was operated in the frequency range 8700–10,100 mc.

The Maser

Theoretical Considerations

The maser was a three-level[11] solid state device using ruby[4] ($Al_2O_3 \cdot 0.01Cr_2O_3$) as the paramagnetic medium. The energy levels of the Cr^{+3} ion in ruby[12,13] are shown as a function of magnetic field H in Fig. 4 for the case of an angle of 60° between the direction of the static magnetic field and the crystal axis of symmetry. The levels are numbered in order of increasing energy and by the quantum number M applicable at high magnetic field, At thermal equilibrium at a bath temperature T, the ratio of the population of level 3 to that of level 2 is the Boltzmann ratio $\exp(-h\nu_{23}/kT)$ and in the high temperature approximation $T > h\nu_{14}/k$

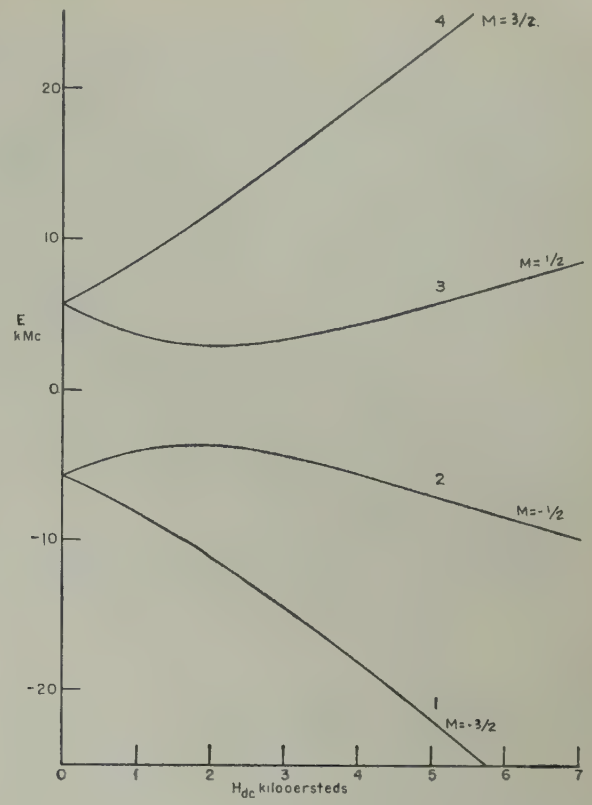


Fig. 4—Energy levels of Cr^{+3} in a ruby as a function of magnetic field for an angle of 60° between the crystal axis of symmetry and the dc magnetic field.

$$n_2 - n_3 \approx \frac{Nh}{4kT}\nu_{23} \tag{12}$$

where N is the total number of spins present, h is Planck's constant, k is Boltzmann's constant, and n_2, n_3 are the populations of levels 2 and 3, respectively.

In the presence of pumping radiation at the frequency ν_{13} sufficient to saturate the transition 1→3 the populations assume new steady state values and

$$n_2 - n_3 = \frac{Nh}{4kT}\left[\frac{-\nu_{12}\left(w_{12} + \dfrac{w_{14}w_{42}}{w_{14}+w_{24}+w_{34}}\right) + \nu_{23}\left(w_{23} + \dfrac{w_{24}w_{43}}{w_{14}+w_{24}+w_{34}}\right)}{\left(w_{12} + \dfrac{w_{14}w_{42}}{w_{14}+w_{24}+w_{34}}\right) + \left(w_{23} + \dfrac{w_{24}w_{43}}{w_{14}+w_{24}+w_{34}}\right)}\right] \tag{13}$$

where w_{ij} sec^{-1} is the transition probability for an ion to relax from level i to level j. The w_{ij} are related to the relaxation times T_{ij} by the relations

$$w_{ij} + w_{ji} = \frac{1}{T_{ij}}$$

[11] N. Bloembergen, "Proposal for a new type solid state maser," *Phys. Rev.*, vol. 104, pp. 324–327; October 15, 1956.

[12] Energy levels can be derived from published tables. See P. M. Parker, "Nuclear quadrupole levels in single crystals," *J. Chem. Phys.*, vol. 24, pp. 1096–1102; October, 1956.

[13] W. S. Chang and A. E. Siegman, "Characteristics of Ruby for Maser Applications," Stanford Electronics Lab. Tech. Rep. No. 156-2; September 30, 1958 (unpublished). The labelling of the levels in this report is opposite that of the present paper.

and

$$w_{ij}/w_{ji} = \exp(-h\nu_{ij}/kT) \quad i < j. \tag{14}$$

Amplification due to stimulated emission at frequency ν_{23} is obtained when the population of level 3 exceeds that of level 2. Thus we obtain from (13) as a condition for amplification at ν_{23},

$$\nu_{12}\left(w_{12} + \frac{w_{14}w_{42}}{w_{14}+w_{24}+w_{34}}\right) > \nu_{23}\left(W_{23} + \frac{w_{24}w_{43}}{w_{14}+w_{24}+w_{34}}\right). \tag{15}$$

A negative quality factor Q_M can be assigned to the amplifying material as indicated

$$Q_M = \frac{2\pi\nu_{23}\dfrac{1}{8\pi}V_c(\overline{H_{rf}^2})_c}{h\nu_{23}(n_2 - n_3)\overline{W}_{32}} = \frac{V_c(H_{rf}^2)_c}{4h(n_2 - n_3)\overline{W}_{32}} \tag{16}$$

where

V_c is the cavity volume,
$(\overline{H_{rf}^2})_c$ is the mean square of the RF magnetic field amplitude over the cavity, and
$\overline{W}_{32}$ is the average probability for an RF induced 3→2 transition.

For the ideal case where M is a good quantum number, the value of $W_{M,M-1}$ is given by

$$W_{M,M-1} = r\frac{\pi^2}{4}\frac{g^2\beta^2}{h^2}H_{rf}^2(S + M)(S - M + 1)g(\nu) \tag{17}$$

where

β is the Bohr magneton 0.93×10^{-20} ergs/gauss,
g is the splitting factor, 2.0 in the case of Cr^{+3} in ruby,
$g(\nu)$ is the normalized[14] line shape of the magnetic resonance,
M is the magnetic quantum number describing the state at high magnetic field, and
S is the effective spin quantum number describing the ion.

Eq. (17) applies when, as is normal, the width of the magnetic resonance is much larger than the amplifier bandwidth. The factor r is a measure of the effectiveness of H_{rf}. For $g\beta H_{DC} \gg |D|$,[15] $r = 1$ for H_{rf} perpendicular to H_{DC} and $r = 0$ for H_{rf} parallel to H_{DC}. For $g\beta H_{DC} \lesssim |D|$ r becomes a function of H_{DC} and the relative orientations of H_{rf}, H_{DC}, and the crystalline axis of symmetry. Tables have been prepared permitting the calculation of r.[13]

In the case of a homogeneously broadened line of Lorentz shape with total width $\Delta\nu_M$ at half power, the peak value of $g(\nu)$ is

$$g(\nu) = \frac{2}{\pi\Delta\nu_M}. \tag{18}$$

[14] $\int_0^\infty g(\nu)d\nu = 1$.
[15] The zero field splitting of Cr^{+3} in ruby is $2D = -11.46$ kmc.

Then the maximum value of W_{32} is given by

$$W_{32} = \frac{8\pi\beta^2 r H_{rf}^2}{h^2\Delta\nu_M} \tag{19}$$

and

$$\overline{W}_{32} = \frac{8\pi\beta^2}{h^2\Delta\nu_M}(\overline{rH_{rf}^2})_{xtal} \equiv \frac{8\pi\beta^2\bar{r}(\overline{H_{rf}^2})_{xtal}}{h^2\Delta\nu_M} \tag{20}$$

where $\overline{(\ )}_c$ and $\overline{(\ )}_{xtal}$ refer to averages over the volumes of the cavity and the ruby, respectively. From (16) and (20)

$$Q_M = \frac{hV_c\Delta\nu_M}{32\pi\beta^2\bar{k}(n_2 - n_3)}\frac{(\overline{H_{rf}^2})_c}{(H_{rf}^2)_{xtal}} = \frac{hV_{xtal}\Delta\nu_M f}{32\pi\beta^2\bar{k}(n_2 - n_3)}, \tag{21}$$

where the cavity filling factor f is defined by

$$f = \frac{V_c(\overline{H_{rf}^2})_c}{V_{xtal}(\overline{H_{rf}^2})_{xtal}}.$$

The filling factor f has a maximum value of unity when the cavity is filled with paramagnetic material. The r factor has a value of unity, for example, at high values of H_{DC} for the case of a TE_{omn} mode in a rectangular cavity with the E field parallel to H_{DC}.

At cavity resonance, the ratio of reflected to incident power, G, is related to Q_e, the external cavity Q, to Q_0 the unloaded Q of the cavity, and to Q_M by

$$\sqrt{G} = \frac{\dfrac{1}{Q_e} - \left(\dfrac{1}{Q_0} + \dfrac{1}{Q_M}\right)}{\dfrac{1}{Q_e} + \left(\dfrac{1}{Q_0} + \dfrac{1}{Q_M}\right)} = \frac{\dfrac{1}{Q_e} + \dfrac{1}{|Q_M|} - \dfrac{1}{Q_0}}{\dfrac{1}{Q_e} - \dfrac{1}{|Q_M|} + \dfrac{1}{Q_0}}. \tag{22}$$

From (22) and the relation $\nu_{23} = Q\Delta\nu_1$ we obtain

$$(\sqrt{G} - 1)\Delta\nu_1 = 2\nu_{23}\left(\frac{1}{|Q_M|} - \frac{1}{Q_0}\right) \tag{23a}$$

$$(\sqrt{G} + 1)\Delta\nu_1 = \frac{2\nu_{23}}{Q_e}. \tag{23b}$$

Thus at high gain the root gain bandwidth product is approximately a constant.

Performance Characteristics

Two masers were constructed and used in the work. The first, designated by I, had a low filling factor. The second, II, whose characteristics were outlined in the Introduction, had a filling factor of almost unity and a near-optimum configuration of H_{rf}. The characteristics of the two masers are summarized in Table II.

The value of N is calculated from the crystal volume and an assumed concentration (Cr/Al) of 0.05 per cent. The rubies were prepared by Linde Air Products Corporation from a mixture with an initial concentration of 0.1 per cent.

TABLE II

MASER CHARACTERISTICS

	Maser I	Maser II
Maser gain-bandwidth, $\sqrt{G}\Delta\nu_1$ mc	10	50
Magnetic Q, Q_M	1800	380
Amplification frequency, ν_{23} mc	9000	9500
Pump frequency, ν_{13} mc	21,000	23,500
Orientation of magnetic field relative to crystal symmetry axis, θ	59°	55°
Static magnetic field, H_{DC} oer.	3360	3740
Unloaded cavity $Q(\nu_{23})$, $Q_0(\nu_{23})$	10,000	7000
Bath temperature, T°K	1.4°	1.4°
Total cavity $Q(\nu_{13})$, $Q(\nu_{13})$	5000	4000
Pumping power mw	30	30
Cavity mode (ν_{23})	TE_{102}	TE_{101}
Cavity volume, V_c cm^3	4.8	0.48
Crystal volume, V_{xtal} cm^3	0.54	0.35
Number of Cr^{+3} ions, N	1.3×10^{19}	8.0×10^{18}
Filling factor, f		0.8
Transition probability factor, F		0.72
Maser bandwidth at half power, $\Delta\nu_M$ mc	200	200

The masers were operated over a range of frequencies between 8700 and 10,100 mc using a variety of cavity modes at the pumping frequency, so that the operating characteristics quoted should be considered only as representative. The value of 50 mc is the value of $\sqrt{G}\Delta\nu_1$ obtained using a small permanent magnet. Under laboratory conditions with higher field homogeneity, a value of $\sqrt{G}\Delta\nu_1 \cong 100$ mc was observed.

An accurate calculation of the expected $\sqrt{G}\Delta\nu_1$ is complicated by lack of detailed knowledge of the transition probabilities w_{ij} between the various levels. A crude estimate of $\sqrt{G}\Delta\nu_1$ for II using the parameters of Table II in (13) and (21), assuming $W_{12}=W_{23}$ and neglecting the effects of $\Delta M=2$ relaxation, gives a value of 48 mc for $\sqrt{G}\Delta\nu_1$. This value is in general agreement with that observed.

The gain stability of the system was usually limited by variations in the impedance at the output of the maser, although small changes in critical mechanical parts or in magnetic field strength sometimes also gave troublesome gain variations. In common with any highly regenerative reflection type amplifier the gain was quite sensitive to the matching of the output load. With a maser gain of 20 db a mismatch introducing a voltage reflection coefficient of 1 per cent could give rise to a gain variation of ± 0.8 db.

Most of the observations with the present system were carried out with an rms gain variation of the order of 0.1 db/min. Most of this variation was periodic with a highly reproducible period of about 44 minutes. This component of the variation was attributed to the impedance variations arising from the moving surface of the liquid helium within the signal waveguide. This source of gain variation was eliminated by filling the signal waveguide with polystyrene foam which displaced the liquid helium. Although the system has not yet been observed over long periods of time with this modification, it appears that the average gain variation with the antenna stationary has been reduced to less than 0.01 db/min. This gain variation is not serious for most astronomical purposes if the ferrite switch connects two sources of noise with effective temperatures that differ by less than 1°.

The sensitivity of the gain to load variations prevented the replacement of the ferrite switch by a mechanical chopping arrangement. The mechanical chopper was installed in the hope of removing the appreciable noise contribution from the ferrite switch.[16] In this arrangement, the signal and comparison horns were connected to terminals 1 and 4, respectively, (Fig. 1) of the circulator. The temperatures seen by the horns were compared by insertion of a motor-driven shorting blade at terminal 1. It was observed that the maser gain with the blade inserted was as much as 3 db greater than the gain with the blade removed. As the blade was inserted and removed higher transient gains were sometimes seen. This type of behavior is consistent with the inadequate isolation of about 22 db provided by the circulator between terminals 2 and 1. To avoid gain variations of this kind the ferrite switch was reinstalled.

Cavity and Coupling Arrangements

In both masers I and II the cavity was a rectangular type supporting a TE_{10n} frequency. In II the amplifying mode was the fundamental TE_{101} mode with the RF electric field approximately parallel to H_{DC}. No identification of the K-band modes was attempted. The density of modes at K-band was large and the mode selection was not found to be critical. Most modes of similar Q appeared to have equivalent effect in driving the system.

The cavity and coupling scheme for II are shown in Fig. 5. The coupling from RG53/U waveguide to the K-band mode was via a fixed iris in the lead window closing the cavity. The lead window was pressed onto the cavity edge by a stainless steel clamp to provide satisfactory electrical contact. The X-band coupling was via a thin inductive post passing across the X-band waveguide and protruding into the cavity along the RF electric field. In the case of I the coupling could only be adjusted internally. As a result, slight and irregular coupling variations accompanying the violent thermal cycling often prevented the optimum coupling from being available after cooling. In II the coupling probe could be adjusted from outside the dewar using a rack and pinion linkage.

The ruby was supported in the cavity of I by a perforated teflon block. The frequency of the cavity could be varied over a range of 800 mc by adjusting the position of the ruby in the teflon block. Frequency adjustments in II were obtained by moving the ruby relative to a dielectric spacer plate in the cavity.

Initially, microphonics were a persistent problem in operating the system. It was found that in I, motion of the antenna caused appreciable gain fluctuations due to small motions of the crystal in the cavity. In II the microphonics were almost completely eliminated by applying pressure to the crystal through spring loaded teflon rods pressing through three of the cavity walls.

[16] This arrangement was suggested by F. Arams.

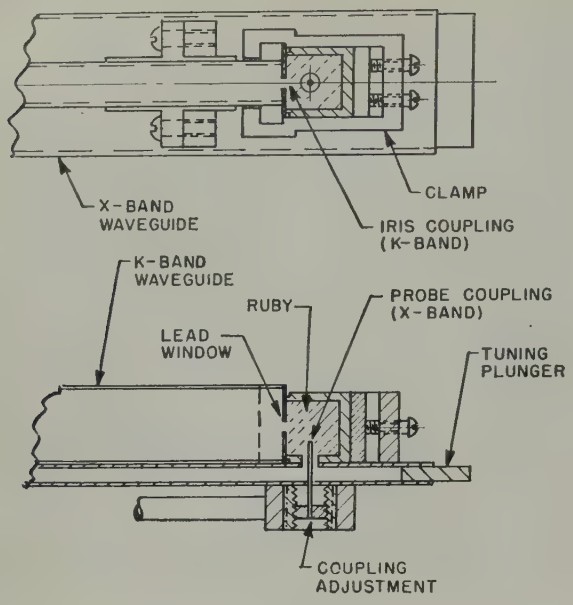


Fig. 5—Cavity and coupling scheme of maser II.

Pumping

Pumping power was provided by a QK306 (21–22 kmc) or 2K33 (22–24 kmc) klystron mounted beside the dewar. At a pumping power of 30 mw no appreciable gain variation was found to be associated with variations in power output of the pump source. A power stabilization circuit using a current controlled ferrite isolator as a power regulator was installed but found unnecessary.

The klystron frequency was stabilized against long term drifts by being locked to an external wavemeter which could be tuned remotely. The stabilization scheme[17] (Fig. 6) involved sweeping the klystron frequency continuously over several hundred kc centered about the wavemeter frequency. By comparing the phase of the sweep frequency component of the crystal detector current with that of the sweep voltage in a lock-in detector, a correction signal was obtained. The correction signal was applied to the klystron repeller through a 2B23 magnetic diode. The klystron frequency was tuned to the cavity resonance by tuning the wavemeter for maximum maser gain. The maser gain was found to be relatively insensitive to driving frequency near the peak of the cavity resonance.

Cryogenic System and Magnet

The elongated stainless steel dewar was of conventional design. The main helium storage chamber was 18 inches inside height and had a capacity of 3 liters. The "finger" extending between the magnet pole pieces was 1 inch ID and $1\frac{1}{2}$ inches OD. The *X*-band waveguide was tapered in both dimensions to fit the finger. Both waveguides were of brass milled to a thickness of

[17] C. H. Townes and A. L. Schawlow, "Microwave Spectroscopy," McGraw-Hill Book Co., Inc., New York, N.Y., p. 484; 1955.

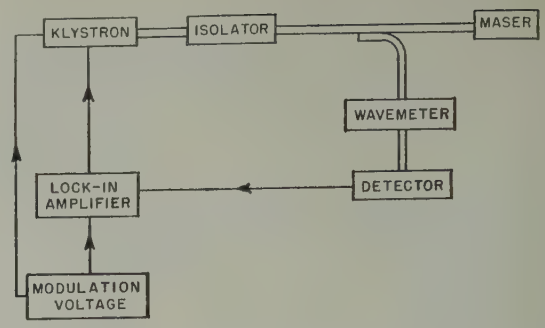


Fig. 6—Schematic diagram of pumping klystron stabilization system.

0.015 inch to minimize helium loss. The dewar was mounted at the focus so as to be vertical at an antenna elevation of 45°, limiting the maximum tilt of the dewar to 45°.

After the dewar was pumped down to a pressure of about 2 mm the remaining helium lasted 12 to 15 hours. The pump was of 15 cubic ft/min capacity and was mounted behind the reflector surface. The 30-foot connection to the focus was via 3-inch tubing.

The system was operated at 1.4°K. Good helium circulation inside the cavity and around the crystal was found to be important for effective cooling in the presence of microwave pumping power. In II the ruby faces were serrated to insure helium circulation around the crystal.

The magnetic field was provided by a modified commercial permanent magnet (No. 5725, Arnold Engineering Co., Marengo, Ill.). The commercial magnet produced a field of 1600 oersteds, with 3.5-inch diameter pole faces and a 3.6-inch diameter pole gap. The magnet was modified by addition of tapered Armco iron pole pieces providing a pole gap of $1\frac{3}{4}$ inches with pole diameter of $1\frac{3}{8}$ inches. Homogeneity of the field was improved by the use of annular shims $\frac{1}{8}$ inch thick by 3/16 inch wide. With the shims and an available pole gap of $1\frac{1}{2}$ inches the maximum available field at the center of the gap was about 3300 oersteds. Operating fields up to 4000 oersteds were obtained by using coils wound around the pole pieces. The coils were operated with a current-regulated power supply, and the field could be regulated within ± 2 oersteds. The magnet was mounted in a cage which could be rotated to any desired angle relative to the ruby crystal symmetry axis.

The Receiver, Mixer, IF Strip, and *X*-Band Components

The receiver system has been described fully by Mayer, *et al.*[10] The characteristics are summarized in Table III.

As discussed in the Introduction, the noise figure of 9.8 db = 10 log F as defined for a receiver without reactive image rejection, indicates an equivalent temperature of $(F-2)290$°K at the input to the mixer on the basis of a 5.5-mc bandpass. Since the continuum signal information is detected over an equivalent 11-mc band-

TABLE III
Receiver Characteristics

Intermediate frequency	= 30 mc
IF bandwidth at ½ power	= 5.5 mc
IF amplifier noise figure	= 2.2 db
Receiver noise figure	= 9.8 db

ass, the noise figure of the system is effectively F/2 and he noise temperature

$$(F/2-1)\ 290°K.$$

The reduction in gain fluctuation "noise" afforded by he ferrite switching technique[10] was found to be es-ential to utilize the improved sensitivity of the maser. The equivalent temperature at the input to the maser is stimated as about 47°K (excluding the ferrite switch). Maser gain variations of 10 per cent during an observa-ion of 6 minutes, a not-uncommon occurrence, would nave been disastrous in the absence of the switching, which reduced the signal from background temperature to the equivalent of a few degrees. To reduce further the effects of maser gain instability, a remotely controlled attenuator was inserted in the comparison horn waveguide permitting the antenna horn and the comparison horn to be balanced to within about 0.3°K. For this degree of balancing a ten per cent gain variation introduced a shift in the zero level of the order of the rms noise level.

Radio Astronomical Observations

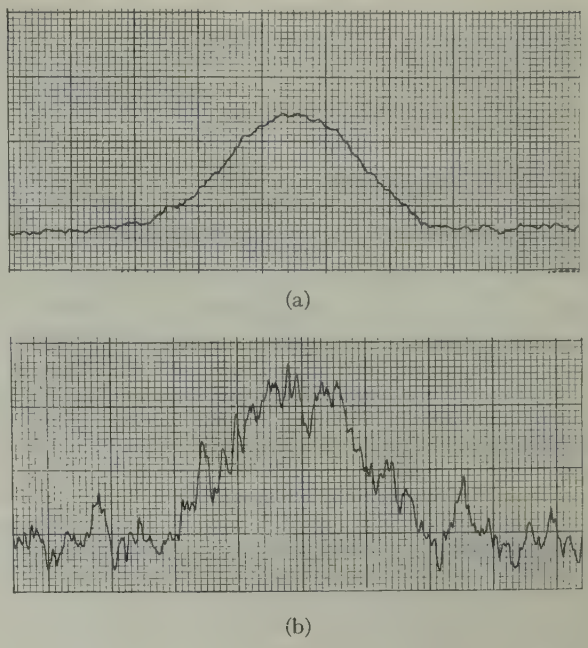
The maser radiometer has been applied to the study of discrete radio sources, in particular the planets Venus and Jupiter. A preliminary account of the early observations of Venus, Jupiter, and Virgo-A (NGC 4486) has been presented[18,19] and detailed results will be published elsewhere.

In Fig. 7 the performance of the maser radiometer (II) is compared with that of the radiometer without the maser. The drift scans of the intense source Cygnus-A (peak antenna temperature 4.6°K) were both obtained using an averaging time of $\tau = 5$ seconds. The rms fluctuation level for the drift scan using the maser radiometer is approximately 0.07°K in Fig. 7.

Fig. 8 is a drift curve of the radio source Virgo-A obtained using the maser radiometer (II) on August 21, 1958. The peak antenna temperature is 1.0° and the rms fluctuation level approximately 0.05°K, for an averaging time of 5 seconds.

Conclusion

This initial application of a maser amplifier indicates the substantial improvement in sensitivity available from maser techniques and the feasibility of using these techniques in radio astronomy. The limitation on noise in such a system lies in the thermal radiation from components and environment preceding the amplifier, in particular from the ferrite switch, the circulator, and the hot ground seen by the antenna. It appears that the contribution from each of these sources can be eliminated or largely reduced, so that noise temperatures near 10°K should be obtainable in carefully designed systems. This, with masers of still wider bandwidth, should allow considerable further improvement of radiometer sensitivity in the microwave range.



(a)

(b)

Fig. 7—Drift scans of the radio source Cygnus-A. The upper curve (a) was taken with the maser radiometer. The lower curve (b) was obtained by using the superheterodyne receiver without the maser preamplifier, and is reproduced through the courtesy of T. McCullough and R. Sloanaker. Peak antenna temperature 4.6°K.

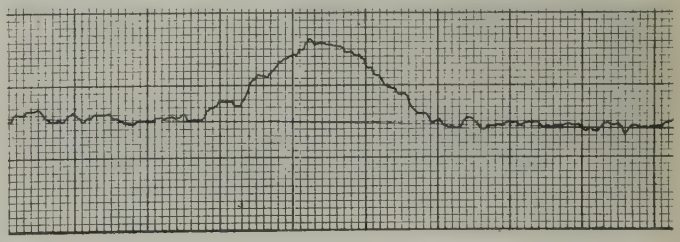


Fig. 8—Drift scan of the radio source Virgo-A obtained with the maser radiometer. Peak antenna temperature 1.0°K.

Acknowledgment

The authors would like to thank Prof. C. Kikuchi for information about experiments with ruby before publication, and for providing the ruby used in this work. They are grateful to E. F. McClain for help in planning this cooperative program and for his support throughout the course of the work, to J. Boland for his assistance in the installation and operation of the equipment, and to I. Beller, C. Dechert, A. Marshall, and R. Sloanaker for their contributions to the design and construction of the apparatus.

[18] L. E. Alsop, J. A. Giordmaine, C. H. Mayer, and C. H. Townes, "Observations using a maser radiometer at 3 cm wavelength," *Astronom. J.*, vol. 63, p. 301; September, 1958.

[19] IAU-URSI Symposium on Radio Astronomy, Paris, France; July 30–August 6, 1958. (To be published in the Symposium report.)

Tantalum Printed Capacitors*

R. W. BERRY† AND D. J. SLOAN†

Summary—It has previously been considered either impossible or impractical to make tantalum oxide capacitors by applying a metal counter electrode directly to a tantalum oxide film. Attempts in this direction have led to either direct shorts or low breakdown strength. For this reason, it has been presumed that it was essential to use either an electrolyte or a semiconductor in the cathode structure.

Using sputtered tantalum films as the base for the anodized oxide film, however, excellent results have been achieved employing evaporated metal counter electrodes. Many of the properties of units made in this way are superior to those of other types of tantalum capacitors.

Capacitances obtained are comparable to the capacitance-area relationships for tantalum electrolytic capacitors formed to the same voltages. DC leakages, however, have been found to be much lower than values reported for those of tantalum electrolytic units. Another advantage is that these units are capable of withstanding higher voltages than will tantalum solid electrolytic capacitors formed to the same voltage. Indeed, voltages equal to the anodizing voltage may be maintained on the capacitor without impairment.

Capacitors have also been produced with thin films of other anodizable metals, evaporated aluminum in particular.

This type of capacitor should find many applications in the lower capacitance areas, and seems ideally suited for printed circuit applications.

Introduction

ELECTROLYTIC capacitors find their major uses when large blocks of capacitance are needed in electrical circuits. No other capacitors provide such large capacitance to volume ratios at a low cost. For lower capacitance applications, however, it has been usual to use mica, paper, ceramics, or some other type capacitor which has a relatively inefficient capacitance to volume ratio. With the present trend toward microminiaturization, lower valued capacitors which maintain the higher capacitance-volume ratio of the electrolytic capacitors should find wide application, particularly if their properties are superior to most electrolytic units available today. Also toward this aim of miniaturization, printed circuit techniques are being utilized to a greater and greater extent, and a capacitor which could be "printed" onto a circuit board, still showing reasonable capacitance values, should be a real aid.

In our laboratories, a capacitor (to be referred to here as a tantalum printed capacitor) has been developed which meets both the above requirements. These units are fundamentally different from electrolytic capacitors in that there is no electrolyte or semiconductor involved in their cathode structure; instead, the electrodes are both metallic. Whereas larger capacitance requirements might call for a capacitor of the solid electrolytic type described previously by McLean and Power,[1] these capacitors should find application in the capacitance range below about 1 μf.

Structural Features

The units to be discussed are made by putting a thin film of tantalum on an insulating substrate, electrochemically oxidizing a portion of the tantalum to form the dielectric layer, and then applying another layer of metal on top of this oxide film. Almost all experimental tests have been performed on units having standard microscope slides as their substrate, but capacitors have also been made on glazed ceramics and other smooth surfaces. The tantalum films were produced by the technique of cathodic sputtering, using appropriate masking to give the desired patterns of tantalum. The majority of the samples were prepared using a 4-inch diameter tantalum (Fansteel capacitor grade sheet) cathode approximately 2 inches from the substrate. The slides were sputtered at a potential of 5000 v for one hour in an argon atmosphere, held at a pressure of 20 microns. This produced films whose thicknesses were of the order of 5000 Angstrom units.

A layer of dielectric tantalum oxide was electrochemically formed on the tantalum surfaces by making the tantalum film the anode in an electrolytic bath. Although various electrolytic solutions were used successfully, most samples were prepared with an electrolyte consisting of one part by weight of oxalic acid, two parts water, and three parts ethylene glycol. The temperature during anodization was maintained at 105°C, and the current kept at about 1 ma per square cm of exposed tantalum until the desired voltage was reached. The anodization was continued for from 4 to 5 hours. The thickness of the oxide, which constitutes the dielectric of the capacitor, is controlled by the formation voltage, to which it is proportional.

The second, or counter, electrode was then put on by evaporating another metal onto the slide through appropriate masks. Both gold and aluminum have been used by the authors, and no difference in properties has been observed between these two different counter electrode materials. Fig. 1 is a diagrammatic representation of a structure comprising five individual test capacitors on a single substrate. Fig. 2 is a photograph of some representative units on both microscope slides and ceramic substrates.

* Original manuscript received by the IRE, December 24, 1958; revised manuscript received, March 5, 1959.

† Bell Telephone Labs., Inc., Murray Hill, N. J.

[1] D. A. McLean and F. S. Power, "Tantalum solid electrolytic capacitors," PROC. IRE, vol. 44, pp. 872–878; July, 1956.

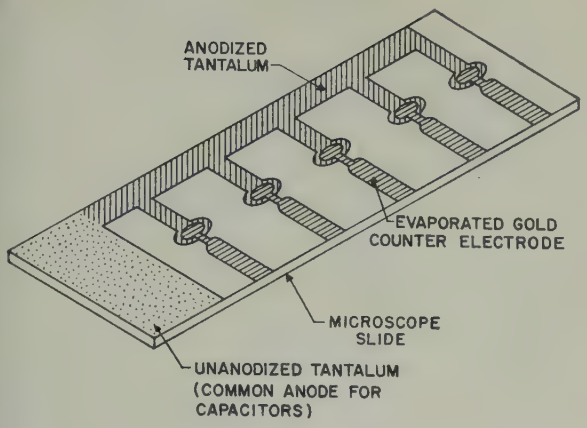


Fig. 1—Drawing showing five test capacitors on a microscope slide.

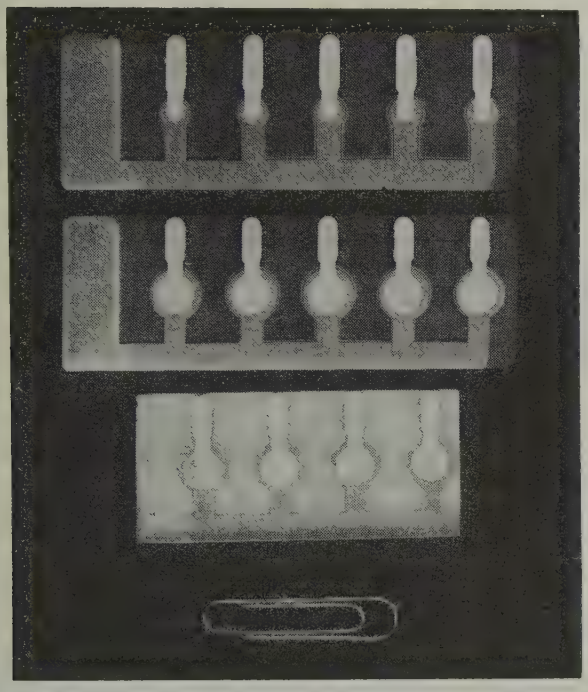


Fig. 2—Photograph of test capacitors on microscope slides and a ceramic substrate.

The capacitance values obtained with these units are, of course, proportional to the area of the electrodes, and above 50 v formation, inversely proportional to the formation voltage. Below 50 v, the capacitance is somewhat less than would be expected, probably because of the existence of the thermal oxide film initially on the samples. The following table gives approximate capacitances obtained with electrodes 250 mils in diameter for various formation voltages:

Formation Voltage	*Capacitance ($\mu\mu f$)*
5	250,000
10	185,000
20	92,000
40	68,000
100	30,000
150	20,000
200	15,000

These capacitors bear some resemblance to electrolytic units, but it is to be re-emphasized that no electrolyte or semiconductor is incorporated in their cathode structure. They, therefore, may be considered electrolytic only in the sense that the dielectric has been formed by standard electrolytic techniques. The use of a metal counter electrode has usually been considered impractical if not impossible, and it has generally been maintained that an electrolyte or semiconductor is required as a part of the cathode system. As discussed below, the success achieved with the structure described here probably results from the perfection of the sputtered tantalum films as compared, for example, with rolled or drawn tantalum pieces.

Temperature Characteristics

These capacitors, containing no electrolyte or semiconductor, have superior temperature characteristics. The capacitance has been measured on several units at temperatures ranging from that of liquid nitrogen (−196°C) to 250°C. A curve illustrating the variation of capacitance with temperature is shown as Fig. 3. The temperature coefficient of capacitance is seen to remain essentially constant at +250 parts per million per degree centigrade over the temperature range of −196°C to +170°C. Above 170°C, the temperature coefficient increases as is shown by the change in slope in Fig. 3.

The dissipation factor measured at a frequency of 1 kc shows a slight increase with temperature at temperatures up to 170°C, as shown in Fig. 4. With a further increase in temperature, the dissipation factor increases appreciably, while at lower temperatures, it should be noted that the change in dissipation factor is uniform and small to temperatures as low as that of liquid nitrogen.

The leakage current of these capacitors is considerably less than that obtained for electrolytic capacitors. Fig. 5 is a plot of leakage current vs temperature for a 3000-$\mu\mu f$ capacitor formed at 150 v. In this figure, two test potentials are shown, *i.e.*, 40 v and 10 v. The temperature scale is reciprocal, and the leakage current logarithmic; thus, the activation energy for conduction may be calculated, since the slope is equal to $-E^*/k$. The values calculated are 17.8 kcal/mole (0.77 ev) for the 40 v measurements and 17.1 kcal/mole (0.74 ev) for the 10 v measurements. A probable interpretation for the close agreement of these results is that the conduction is electronic in nature, since there is no dependence of the activation energy on potential, at least within these limits.[2] It should be noted here that the room temperature characteristics were unaltered by these excursions to temperature extremes.

[2] C. P. Bean, J. C. Fisher, and D. A. Vermilyea, "Ionic conductivity of tantalum oxide at very high fields," *Phys. Rev.*, vol. 101, pp. 551–554; January, 1956.

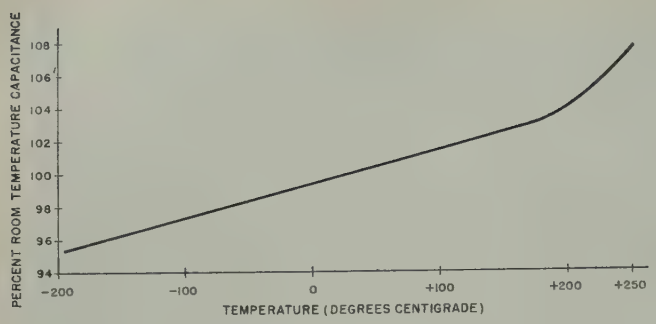


Fig. 3—Capacitance-temperature relationship typical of tantalum printed capacitors.

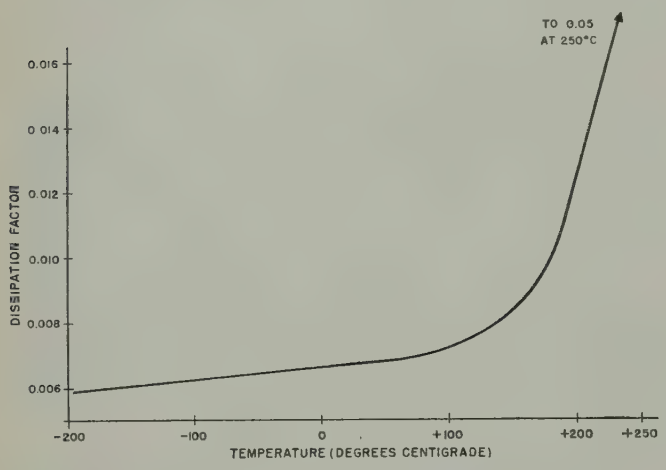


Fig. 4—Dissipation factor-temperature relationship typical of tantalum printed capacitors with 95-mil electrodes.

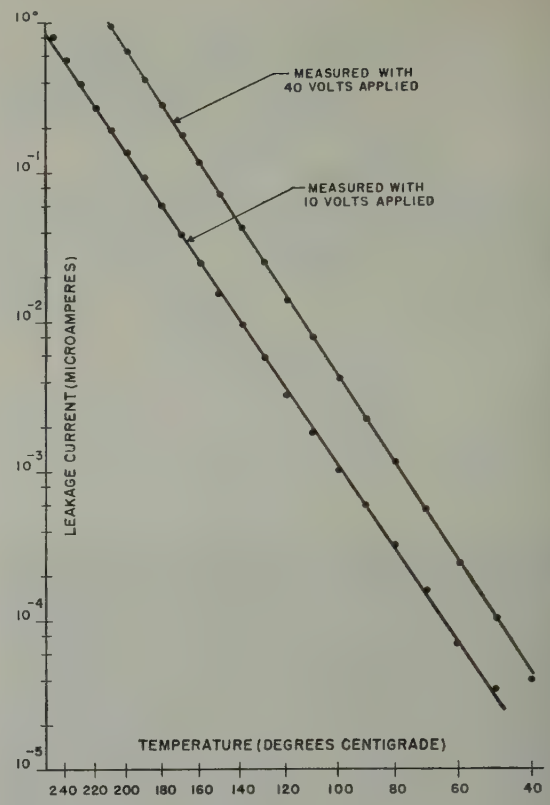


Fig. 5—Leakage current vs temperature for a 3000-$\mu\mu$f tantalum printed capacitor formed at 150 v.

Potential	ρ *(ohm-cm)*
100 v	9×10^{15}
80 v	2.8×10^{16}
60 v	5.7×10^{16}

Room temperature leakages were measured by applying voltages to the capacitors and measuring the current flowing as a function of time. The units exhibit a long polarization time, particularly at the higher voltages. This is shown graphically in Fig. 6, which shows typical plots of the apparent resistances, as a function of time, for a 30,000-$\mu\mu$f capacitor formed to 100 v when measured at different voltages. It is remarkable that although the full formation voltage is applied, (which represents a field strength of about 5 million v/cm) the apparent resistance rises to a value greater than 500,000 megohms after 4 hours. In terms of insulation resistance, this corresponds to approximately 15,000 ohm farads. At lower voltages, the apparent resistance increases, and at 60 v, it is of the order of 4,000,000 megohms, which corresponds to approximately 120,000 ohm farads. It was not possible to obtain accurate data at 50 v and below, because of insufficient sensitivity in the measuring equipment. It should be pointed out that these leakages are equal to or lower than the leakages of ordinary molded mica capacitors of the same capacitance values.

The apparent volume resistivities have been calculated from these data giving the following results at the various test potentials:

These values are in excess of any previously reported, but they probably do not represent intrinsic behavior.

In order to observe whether these units were polar, measurements were made in the following manner: Current was plotted on the y axis of an x-y recorder, while the potential, plotted on the x axis, was slowly increased. This was done both with the tantalum positive (anode) and negative. The majority of the current seen was the charging current of the capacitors, but by subtracting this, a comparison of the conduction properties in the two directions could be made. (It should be noted that this method will include any polarization current.) Such a plot with the instantaneous charging current subtracted is shown as Fig. 7. The capacitors are asymmetric, but rather than showing a sharp increase in current at very low voltages when the tantalum is cathodic, this increase in current is exhibited at anywhere from 10 to 40 per cent of the formation voltage. The actual behavior of the units is peculiar, however, in that they often may appear to be nonpolar even to voltages approaching that of formation. If allowed to remain at these high voltages, however, they usually begin to exhibit higher leakages, and a return trace shows its change in slope somewhere within the range mentioned above. It should be noted that the leakage character-

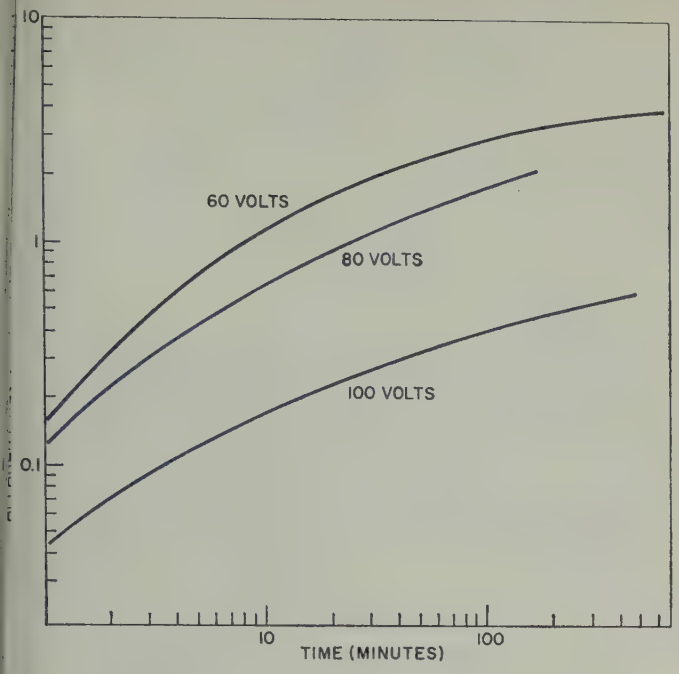


Fig. 6—Apparent resistance vs time, as measured at several potentials, for a 30,000-$\mu\mu$f tantalum printed capacitor formed to 100 v.

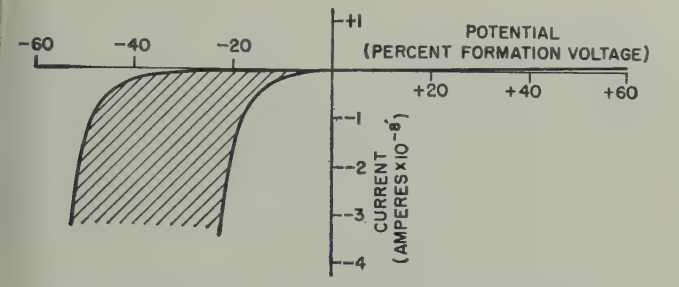


Fig. 7—Instantaneous leakage vs voltage for 95-mil tantalum printed capacitors formed to from 10 to 200 v.

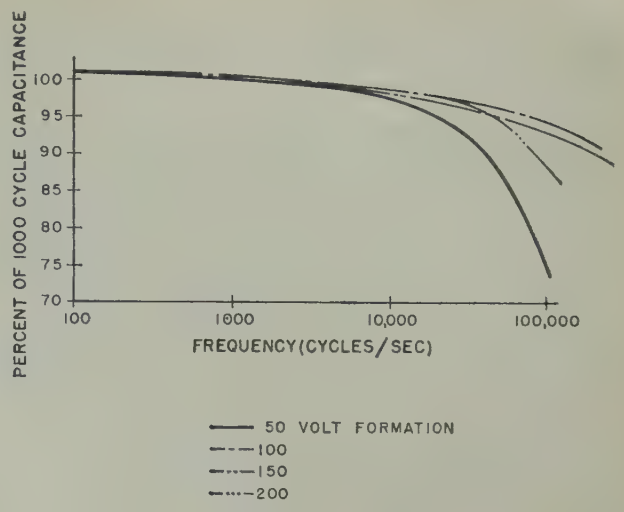


Fig. 8—Capacitance-frequency relationships for tantalum printed capacitors formed at various voltages.

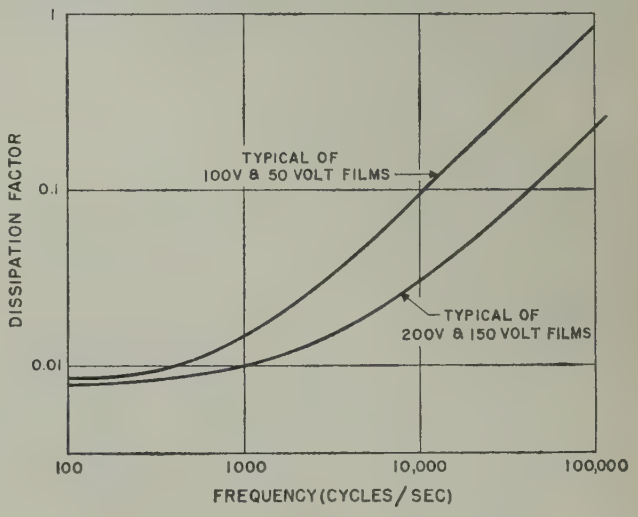


Fig. 9—Dissipation factor-frequency relationships for tantalum printed capacitors formed at various voltages.

istics with the tantalum positive are unchanged by this application of reverse potential. This indicates that a momentary application of substantial voltage in the reverse direction may be tolerated without damaging the capacitors.

In an attempt to make a nonpolar unit, a tantalum counter electrode was sputtered on, with the object of making a symmetrical capacitor. Although the capacitors produced were essentially nonpolar, their leakages were higher than the reverse leakages of the nonsymmetrical units. It is believed that the sputtering process used in applying the tantalum counter electrode may have injured the oxide film, since the same high leakages are observed if a gold counter electrode be sputtered on instead of evaporated.

The breakdown strength of these capacitors approximates their formation voltage more closely than has been previously realized in truly dry tantalum units. It is not suggested, however, that the capacitors be used at these voltages. As it will be pointed out below, operation at one half the formation voltage may well be possible at temperatures up to 65°C.

Frequency Characteristics

The high frequency limitations of these capacitors are less pronounced than in the case of normal aqueous electrolytic capacitors. The frequency characteristics are illustrated in Figs. 8 and 9. Fig. 8 shows several capacitance-frequency curves for different formation voltages. The pronounced decrease in capacitance at high frequency does not show up until frequencies of the order of 50 to 100 kc are reached. In Fig. 9, plots of dissipation factor vs frequency are shown. These curves show that the dissipation factor increases with frequency in such a manner as to indicate the series resistance of the units to be the major factor affecting the performance at high frequencies.

The logarithmic plots of Fig. 9 approach a 45° slope

at the higher frequencies, which is to be expected if the series resistance is the controlling factor in the dissipation factor at these frequencies. This follows from the fact that the dissipation factor for a series RC circuit is equal to ωCR, where C is the capacitance, R the series resistance, and ω is 2π times the frequency. Furthermore, it will be noted that the capacitors formed at 150 and 200 v have better high-frequency characteristics than those formed at 50 and 100 v. This can be attributed primarily to the lower capacitance, the value of R remaining substantially the same. At low frequencies, ωCR decreases, so that at 100 c, the dissipation factors of the capacitors are essentially equal, being controlled by the dissipation in the tantalum oxide film.

The high frequency characteristics can best be improved by decreasing the series resistance of the units. This may be done in a number of ways, the easiest being to shorten the length of the tantalum leads and to increase the thickness of the tantalum films. Alternatively, the tantalum might be put down on an underlying layer of another metal.

Life Tests

It is difficult to collect life test data on new components during the period of active development, since samples used for life tests may be obsolete before the tests are complete. Nevertheless, eighteen units formed to 100 v have been on test at room temperature and at 75 v for a period of over 6 months, with no failures, and no important changes in electrical properties. At 85°C, however, with 70 v applied, eighteen of twenty-eight capacitors formed to 100 v had opened in 2 weeks. The failures apparently occurred via the process of momentary short circuits burning off the gold counter electrodes. The ten remaining capacitors did not change appreciably in any respect after 5 weeks when the test was stopped. With another group of 25 units also formed to 100 v, life testing at 85°C and 50 v is now in progress. No failures have occurred nor have any changes in electrical characteristics been observed over a 7-week period, but this is a very short time for any conclusions to be drawn. Many additional life tests must be performed on larger numbers of capacitors before any voltage ratings are assigned, although it appears that half the formation voltage would be a conservative rating up to 65°C.

Other Structures

Only single layer capacitors have been discussed thus far, but several multilayered units have been made as follows: A thin substrate (a microscope cover glass) is coated with tantalum, leaving one edge free of metal; this tantalum is then anodized, and gold evaporated on, leaving an edge of tantalum free from gold. Several of these are then stacked together, and a lead is put on each side with silver paste. The construction is shown schematically in Fig. 10. Utilizing such a structure, with substrates 10 mils thick (the approximate thickness of a microscope cover glass) and allowing one half the volume for margins, etc., the capacitance available per cubic inch for a 100 v formation would be in the order of 50 μf. This could be increased substantially by decreasing the substrate thickness. Exploratory samples, only two layers thick, have a capacitance of 0.15 μf and a volume of 0.009 cubic inch.

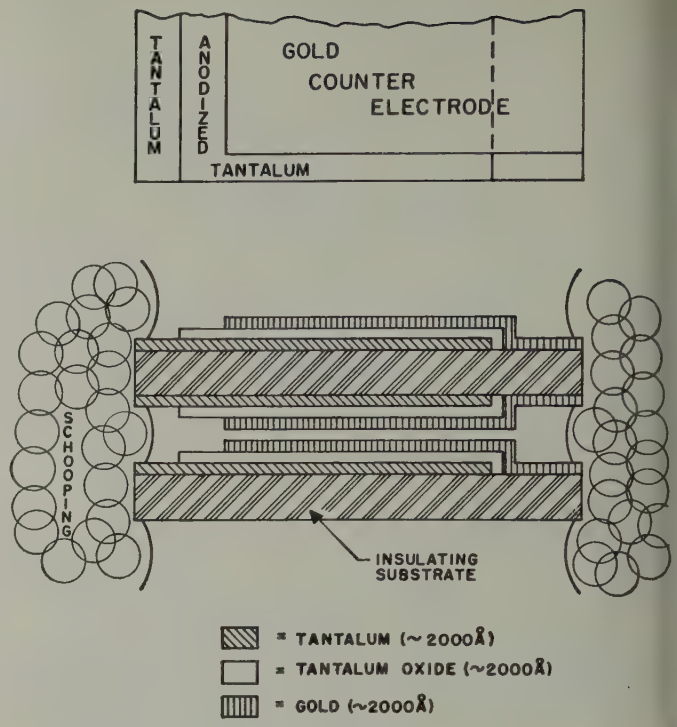


Fig. 10—Schematic representation of a multilayered capacitor.

Other Metals

It has not previously been considered practical to make reliable capacitors by putting a metal electrode next to an electrochemically-formed oxide film. In the opinion of the authors, the limited success achieved with capacitors of this sort on bulk tantalum has probably been due to the presence of point concentrations of impurities on the surface, such as might be introduced in the mechanical forming of the metal. Indeed, the conduction properties of tantalum oxide formed on foil have been attributed to these impurity centers.[3] Any impurities in the sputtered films, however, would be distributed uniformly throughout the film, accounting for the much improved results reported here.

In the hope that conduction properties of anodic films of other metals might also be attributed to such centers, studies are now being made using evaporated films of aluminum and titanium, as well as sputtered films of niobium.

Good preliminary results have been obtained for capacitors made from aluminum, but the titanium and

[3] D. A. Vermilyea, "On the mechanism of electrolytic rectification," *J. Appl. Phys.*, vol. 27, pp. 963–964; August, 1956.

bbium films have produced units with low breakdown rength. Further work is being done with these other m-forming metals as well as with tantalum.

Conclusions

A new tantalum capacitor, essentially two-dimenonal in structure, has been made and has properties perior to other types of tantalum capacitors.

Capacitances obtained are comparable to the capaciance-area relationships for tantalum electrolytic caacitors formed to the same voltages. Using counter ectrodes of 95 mils to 250 mils in diameter and the ngle-layered structure, capacitors have been prepared ith capacitances ranging between about 2000 $\mu\mu$f and .25 μf.

DC leakages measured at three-quarters the formaion voltages are of the order of 4×10^{-11} a for 250-mil iameter electrodes. Expressed in terms of insulation reistance, this amounts to about 60,000 ohm farads.

Dissipation factors are in the neighborhood of 0.008 t 100 c and increase to between 0.1 and 0.8 at 100 kc. The relatively high losses at the higher frequencies are caused by the high series resistance of the tantalum films. Thicker films of tantalum should reduce these losses.

Room temperature breakdown voltages approximate the formation voltages for these units, and successful models have been formed to 5, 10, 20, 30, 40, 50, 100, 150, and 200 v. A suggested working voltage is one half the formation voltage for temperatures up to 65°C. Voltage derating characteristics for elevated temperature operation have not been determined as yet. The units operate well at very low temperatures, however, even down to −196°C.

This type of capacitor should find many applications in the lower capacitance areas, and seems ideally suited for printed circuit applications.

Acknowledgment

The authors are indebted to D. A. McLean and N. Schwartz for many helpful discussions, and to H. Basseches for aid with the sputtering technique.

Linear Diversity Combining Techniques*

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Summary—**This paper provides analyses of three types of diversity combining systems in practical use. These are: selection diversity, maximal-ratio diversity, and equal-gain diversity systems. Quantitative measures of the relative performance (under realistic conditions) of the three systems are provided. The effects of various departures from ideal conditions, such as non-Rayleigh fading and partially coherent signal or noise voltages, are considered. Some discussion is also included of the relative merits of predetection and postdetection combining and of the problems in determining and using long-term distributions. The principal results are given in graphs and tables, useful in system design. It is seen that the simplest possible combiner, the equal-gain system, will generally yield performance essentially equivalent to the maximum obtainable from any quasi-linear system. The principal application of the results is to diversity communication systems and the discussion is set in that context, but many of the results are also applicable to certain radar and navigation systems.**

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I. Introduction

WHEN a steady-state, single-frequency radio wave is transmitted over a long path, the envelope amplitude of the received signal is observed to fluctuate in time. This phenomenon is known as fading, and its existence constitutes one of the boundary conditions of radio system design. It is observed that if two or more radio channels are sufficiently separated in space, frequency, or time, and sometimes in polarization, then the fading on the various channels is more or less independent; *i.e.*, it is then relatively rare for all the channels to fade together. The standard techniques for reducing the effect of fading—known as diversity techniques—make use of this fact. The object of these techniques is to make use of the several received signals to improve the realized signal-to-noise ratio, or to improve some other performance criterion.

Several diversity combining and switching techniques are known, and there have been numerous papers on

this subject in recent years. (A sample of these, with comments, is indicated in a Bibliography at the end; these papers will be referenced by numbers in square brackets, running footnotes by superscript.) However, very few of these have provided quantitative comparative data on the relative performance of the various techniques, especially the two significant techniques (maximal-ratio and equal-gain) investigated since 1954. The major exception to this is a paper by Altman and Sichak [8], which is not widely known and even less understood.

Furthermore, there has been little attempt to explain the fundamental concepts and principles involved. For such reasons, therefore, it appeared desirable to provide an expository treatment of a comparative analysis, within a unified framework, of the three most promising diversity techniques presently known. An earlier memorandum[1] aimed at these objectives indicated that such a treatment might be of fairly general interest.

Of course, in an undertaking of this kind, several previously published results are naturally included as individual cases, though the available information will also be rounded out in a number of ways. Specifically, this paper includes the following material that the author has not seen published elsewhere:

1) A careful statement of the idealized circumstances required for canonical performance of coherent combiners (Section II),

2) Simple expressions for the mean signal-to-noise power ratios of various combiners [(18), (28), and (44); Fig. 8; Table I],

3) Probability distribution curves for equal-gain combiners for 3, 4, 6, and 8 channels (Figs. 10–13, Table II),

4) Estimates of the relative performance of three standard combiners for non-Rayleigh fading (Section VII),

5) A discussion of the relative performance of three standard combiners for correlated fading (Section VIII),

6) Estimates of the degradation of the average performance of equal-gain and maximal-ratio combiners caused by correlated noise voltages (Section X),

7) A bound (due to Stein) on the degradation of coherent-type combiners with imperfectly coherent signals (Section XII),

8) Certain aspects of the determination, meaning, and use of long-term distributions (Section XIII).

In addition, some previously published material has been simplified or otherwise clarified.

It should be mentioned that the criteria employed below are expressed entirely in terms of SNR. This has sometimes been taken to mean that the results were principally applicable to continuous signals, although they are also applicable to certain binary or other discrete signals and can be translated into error rates once a suitable detection characteristic is either theoretically or experimentally known. But in the case of binary systems, it is possible to obtain more specific and precise results on error rates for specific systems. Such results have been extensively studied by Pierce [10], [15] and others and are not considered below. Neither is there a discussion of the considerable benefits obtainable by coding or other signal preprocessing techniques designed to counteract fading, several of which are currently under investigation by other workers.

On the other hand, it should be noted that radar and navigation systems in which a repetitive-addition signal-enhancement technique is employed are closely similar, in some respects, to certain diversity systems. Although radar and navigation systems are not discussed in detail below, many of the results and discussions set forth there are directly applicable to such systems.

II. Basic Assumptions and Other Preliminaries

The principal background required of the reader is a basic acquaintance with certain elementary notions of probability and statistics, essentially equivalent to those developed in the first six pages of a highly readable tutorial paper given by Bennett.[2] No advanced techniques are required here. However, we shall make frequent use of a few ideas and techniques that were not particularly emphasized by Bennett, and a brief exposition of these is given in Appendix I. All probability distributions used in this paper will be interpreted as explained there.

We shall be concerned throughout with random variables given as functions of time (waveforms) in various intervals. In this setting, time and distribution averages are one and the same thing so $\bar{f}$ or $\langle f \rangle$ or $\bar{x}$ or $\langle x \rangle$ for such averages will be written interchangeably, but it is important to note at the outset that our averages will refer to intervals of different durations. Specifically, intervals of three different durations will be considered: 1) Short intervals, whose duration will be denoted by T. The requirement for T is that it must be short in comparison to the time required for the fading amplitude to change appreciably, but long in comparison to the period of the lowest frequency of interest in the signal. Specific representative values of T would range from a few microseconds to a few milliseconds. 2) Intermediate intervals, whose duration will be denoted by T_1. The requirements T_1 must satisfy are rather complicated and will be explained at various points below. Specific suitable values of T_1 would range from a few minutes to a few hours. 3) Long intervals, whose duration will be denoted by T_2. Values of T_2 would range from one month to one year or more.

These intervals will be employed as follows. The short intervals of length T will be used to form "local" statis-

[1] D. G. Brennan, "Linear techniques in diversity communication," March, 1956. (Unpublished memorandum.)

[2] W. R. Bennett, "Methods of solving noise problems," Proc. IRE, vol. 44, pp. 609–638; May, 1956.

s. For example, suppose $e_1(t)$ is the instantaneous nal voltage and $e_2(t)$ is the instantaneous noise voltage some circuit. Then

$$x(t) = \left[\frac{1}{T}\int_{t-T}^{t} [e_1(\tau)]^2 d\tau\right]^{1/2} = \sqrt{\langle e_1^2 \rangle} \qquad (1)$$

d

$$y(t) = \left[\frac{1}{T}\int_{t-T}^{t} [e_2(\tau)]^2 d\tau\right]^{1/2} = \sqrt{\langle e_2^2 \rangle} \qquad (2)$$

uld be the local rms signal and local rms noise, re-ectively, and x^2 and y^2 would be the local mean-square nal and noise voltages. Letting R denote the circuit sistance, x^2/R would be the local average signal power time t, obtained by averaging e_1^2 over the last T conds to find $x^2(t)$. This averaging could be performed, r example, by feeding e_1^2 into a suitable linear filter. ternatively, one could determine the distribution of e_1 the interval $[t-T, t]$ and obtain $x^2(t)$ as the second oment of the distribution, though distributions in tervals of length T will not actually be of concern here. Local statistics such as (1) and (2) will generally ıctuate in time because of fading and other effects. or example, the local rms SNR $x(t)/y(t)$ and the local gnal-to-noise power ratio

$$p(t) = \frac{x^2(t)}{y^2(t)} \qquad (3)$$

ill usually vary over wide limits, though they will be uch better behaved than the (meaningless) instan-neous ratio $e_1(t)/e_2(t)$. The behavior of variables such the local statistic (3) in intervals of length T_1, where $_1 \gg T$, will be studied. In particular, various distribu-ons and averages relative to intervals of length T_1 will e considered. Such T_1-distributions and T_1-averages ill also change with time, in ways discussed in Sections II and XIII. Performance relative to T_1-intervals un-er standard conditions is summarized in Section VI.

Finally, the variability of certain T_1-averages will be onsidered in intervals of length T_2, where $T_2 \gg T_1$. This done in Section XIII. It is usually assumed in system esign that, for suitable values of T_2, all distributions for ie system in question will be essentially the same in very corresponding interval of length T_2. (A suitable alue might be one year, for example.) This is in marked ontrast to the situation for T_1-distributions. However, is found experimentally that this assumption is a easonable first approximation; moreover, if this as-ımption were not satisfied, there would be no method vailable for predicting the performance of the system, least at the present time.

By concentrating on system behavior relative to such escribed lengths of intervals, it is possible to keep the lation between theory and experiment clearly visible, cluding, in particular, the practicable experiments re-uired to verify theoretical predictions. This procedure therefore vital to a complete and realistic analysis of communication systems in general and diversity systems in particular.

In general, the term "diversity system" refers to a system in which one has available two or more closely similar copies of some desired signal. For example, certain radar systems operate by storing the signal received during one scan and adding this to the signal received during the next scan. If $f_1(t)$ is written for the output of the storage device and $f_2(t)$ for the signal currently being received, then the composite signal is simply $f_1(t)+f_2(t)=f(t)$. Now, $f_1(t)$ may consist of a desired message component $s_1(t)$ and an undesired additive noise component $n_1(t)$, so that $f_1(t)=s_1(t)+n_1(t)$, and similarly $f_2(t)=s_2(t)+n_2(t)$. Hence, the composite signal may be written

$$f(t) = [s_1(t) + s_2(t)] + [n_1(t) + n_2(t)], \qquad (4)$$

i.e., in the form of a resultant message component (s_1+s_2) plus a resultant noise component (n_1+n_2). If the message components s_1 and s_2 are closely similar, their sum s_1+s_2 will simply approximate an enlarged copy of either s_1 or s_2. On the other hand, the noise components n_1 and n_2 may be quite dissimilar; one may be negative part of the time the other is positive, and vice versa, so they may partially cancel for part of the time. The sum (4) may then be a better signal than either f_1 or f_2 alone; in particular, $f(t)$ may have a higher local SNR $p(t)$, defined as in (1)–(3), with $e_1=s_1+s_2$, $e_2=n_1+n_2$ than either f_1 or f_2 alone. Thus, one way of using two similar or suitably related copies, f_1 and f_2, may be simply to add them together. Certain navigation systems in which a periodic signal is transmitted also use this storage-and-addition principle.

More generally, one may have N such copies $f_1(t)$, $f_2(t)$, $\cdots$, $f_N(t)$, each of the form $f_j(t)=s_j(t)+n_j(t)$, and one may form the sum

$$f(t) = f_1(t) + f_2(t) + \cdots + f_N(t) = \sum_{j=1}^{N} f_j(t), \qquad (5)$$

which may outperform, in some sense, the individual f_j. However, in view of the fact that the f_j will have fluctuating local statistics, it will be convenient to consider weighted sums of the f_j; that is, the general linear combination will be considered:

$$f(t) = a_1 f_1(t) + \cdots + a_N f_N(t) = \sum_{j=1}^{N} a_j f_j(t), \qquad (6)$$

in which each f_j is weighted by a combining coefficient a_j, which is proportional to the channel gain and may be allowed to vary in accordance with the fluctuating local statistics of the $f_j(t)$. However, the cases to be considered will be those in which the a_j are locally constant, or at least approximately so. The adjective "linear" in the title of this paper stems from (6). Since the a_j may be allowed to vary, depending on the f_j, one should perhaps speak of (6) as locally linear or "quasi-linear." Evidently (4) is simply the case of (6) in which $N=2$, $a_1=a_2=1$.

In diversity communication systems, there are several known methods of obtaining two or more signals f_j, and several known methods of combining these to obtain an improved signal. However, all of the latter methods in current practical use are special cases of (6). Let us first consider briefly methods of obtaining several suitable f_j. The simplest of these is that in which a single transmitting antenna furnishes a signal to several well-separated remote receiving antennas; this method is called space diversity. A variant of this, suitable for use in systems operating at UHF and above, uses two separated transmitting antennas, one of which transmits vertically polarized radiation and the other of which transmits horizontally polarized radiation, and a single receiving reflector with two feed horns or dipoles to separate the vertical and horizontal received signals. By combining these two methods, Altman and Sichak [8] obtained a fourth-order, bidirectional, full duplex space diversity system that requires only two reflectors at each end, as indicated in Fig. 1. (However, it should be added that recent experimental evidence indicates that the fading on the crossed pair of paths is more highly correlated than on the other pairs of paths.) In one form or another, space diversity has been the most commonly used form of diversity communication.

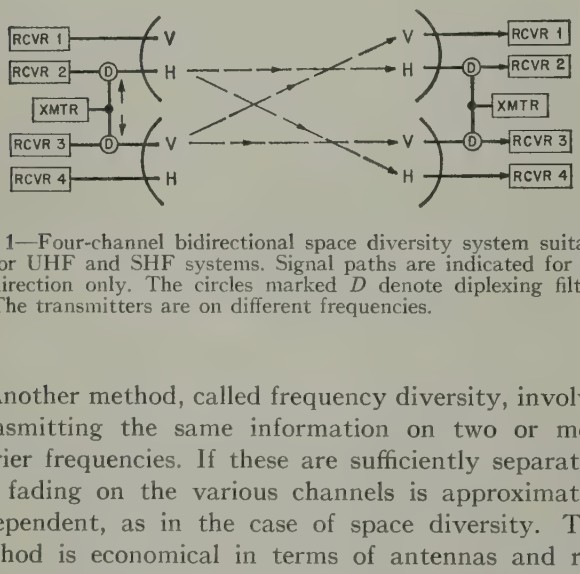

Fig. 1—Four-channel bidirectional space diversity system suitable for UHF and SHF systems. Signal paths are indicated for one direction only. The circles marked *D* denote diplexing filters. The transmitters are on different frequencies.

Another method, called frequency diversity, involves transmitting the same information on two or more carrier frequencies. If these are sufficiently separated, the fading on the various channels is approximately independent, as in the case of space diversity. This method is economical in terms of antennas and real estate, but expensive in terms of transmitters and required bandwidth. It has been discussed more often than used. (However, there are circumstances in which it is useful and has actually been used.) This is also true of the method called time diversity, so far as communication systems are concerned; however, it is not true of radar and navigation systems, as the method discussed in the opening paragraph of this section is essentially time diversity, although this terminology has not been much used in the radar field. In radio communication systems, time diversity involves transmitting the same information two or more distinct times. When this is instrumented for automatic operation, its chief disadvantage is equipment complexity; however, the simple practice of sending each word twice, as used by many commercial CW stations, is actually a primitive but useful form of time diversity. At the other extreme, a very sophisticated communication system, currently under development,[3] which is designed to eliminate effects due to multiple transmission paths between fixed antennas, actually sorts out the various multipath contributions and recombines them with suitable delay and may be regarded as a form of time diversity in which the diversity is provided by the transmission medium itself.

A method that will sometimes yield two approximately independent fading signals is called polarization diversity. In normal ionospheric transmission at frequencies of a few megacycles, it is found that the received signal includes both vertically and horizontally polarized components, and the fading of these components is approximately independent.[4,5] However, in tropospheric transmission at UHF and above, the polarization of the transmitted signal is quite well preserved and very little effect of this type takes place. Furthermore, even if both horizontal and vertical components are transmitted and separately received, the fading of the two components is far from independent if only a single transmission path is involved.[6]

Another method that has been used (infrequently) in the high-frequency region involves the combination of signals arriving with different angles of arrival (the Musa system).[7] A somewhat similar approach at UHF and above is currently under investigation by several workers,[8–10] but the efficacy of this technique is not yet firmly established.

Whichever of these methods is used, the signals obtained will initially be at radio frequency. The diversity combining techniques employed subsequent to this stage may be classed in two groups: predetection combining

[3] R. Price and P. E. Green, Jr., "A communication technique for multipath channels," Proc. IRE, vol. 46, pp. 555–570; March 1958.

[4] J. L. Glaser and L. P. Faber, "Evaluation of polarization diversity performance," Proc. IRE, vol. 41, pp. 1774–1778; December 1953.

[5] G. L. Grisdale, J. G. Morris, and D. S. Palmer, "Fading of long-distance radio signals and a comparison of space- and polarization-diversity reception in the 6–18 mc range," *Proc. IEE*, pt. B, vol. 104, pp. 39–51; January, 1957.

[6] J. H. Chisholm, P. A. Portmann, J. T. deBettencourt, and J. P. Roche, "Investigations of the angular scattering and multipath properties of tropospheric propagation of short radio waves beyond the horizon," Proc. IRE, vol. 43, pp. 1317–1335; October, 1955. See especially Fig. 20, p. 1331.

[7] F. E. Terman, "Radio Engineers Handbook," McGraw-Hill Book Co., Inc., New York, N.Y., pp. 660–661; 1943. See also papers by Polkington and Friis and Feldman cited therein.

[8] R. Bolgiano, Jr., N. H. Bryant, and W. E. Gordon, "Diversity Reception in Scatter Communication with Emphasis on Angle Diversity," Cornell Univ., Ithaca, N. Y., Elec. Engrg. Res. Rep. 35, January, 1958.

[9] A. T. Waterman, Jr., "A rapid beam-swinging experiment on transhorizon propagation," IRE Trans. on Antennas and Propagation, vol. AP-6, pp. 338–340; October, 1958.

[10] J. H. Chisholm, L. P. Rainville, J. F. Roche, and H. G. Rock, "Angular diversity reception at 2290 mcps over a 188-mile path," presented at Symp. on Extended Range and Space Communication, George Washington Univ., Washington, D. C.; October, 6–8, 1958. (Published in the Symp. Rec.)

hods and postdetection combining methods. In se methods in which, at any given time, only one of a_j in (6) is different from zero, *i.e.*, a switch of some d, the distinction is basically unimportant. However, portant differences arise when the combining method ne in which two or more of the a_j may be different n zero at the same time. For example, it is clear that simple addition scheme (4) can fail grievously if the ssage components $s_1(t)$ and $s_2(t)$ are not in the same se, and RF or IF diversity signals will not usually in the same phase unless special measures are taken insure this. Consequently, such combining methods uire special phase-control provisions when used in detection applications, while this is not always the e in postdetection applications. An even more im- rtant difference arises in the case of FM or other ndwidth-exchange systems, where predetection com- ing can lead to substantial improvement over post- ection methods, as will be seen.

Once the method of providing a multiplicity of sig- ls is decided, the basic problem confronting the de- ner of a diversity system becomes one of choosing e most appropriate method of combining these sig- ls on the basis of reasonably accurate quantitative imates of the performance of the various techniques. he balance of this paper is principally devoted to this oblem. Instrumentation problems as such are not nsidered here; however, papers which describe certain strumentation techniques are indicated.

We shall find it most economical to consider first a rticular class of circumstances, and then indicate the y in which the results are modified by other circum- ances or, in some cases, indicate where such modifica- ns are treated elsewhere in the literature. The circum- ances initially considered are those often applicable to stdetection combining in an AM system, or a single- leband system in which provision is made for main- ining coherence of the postdetection signals.[11] These nditions are as follows: assume that N simultaneous nctions, $f_1(t)$, $f_2(t)$, $\cdots$, $f_N(t)$ represent the signals ceived in N different diversity channels as corrupted noise and fading; each f_j, $j=1, 2, \cdots, N$ represents e corrupted signal in the jth channel containing the iginally transmitted signal $m(t)$. For convenience, sup- se that $m(t)$ is a steady test tone at a representative idband frequency, or some other steady test signal th a constant local mean square $\overline{m^2}=1$. That the fol- wing conditions are approximately satisfied is also sumed:

(**A**) The noise in each channel is independent of the gnal, and additive: $f_j(t)=s_j(t)+n_j(t)$ where s_j and n_j e the signal and noise components, respectively, in the channel.

(**B**) The signals $s_j(t)$ are locally coherent; *i.e.*, $s_j(t)=x_jm(t)$, where the x_j are positive real numbers that change with time because of fading, but at a rate that is very slow in comparison to the instantaneous variations of $m(t)$. More precisely, assume that the x_j do not change appreciably within any period of duration T, where T is the duration of the interval employed for the local averages. Then, since $\overline{m^2}=1$,

$$\overline{s_j^2} = \frac{1}{T}\int_{t-T}^{t}[s_j(\tau)]^2d\tau = \frac{1}{T}\int_{t-T}^{t}x_j^2[m(\tau)]^2d\tau$$

$$= x_j^2\cdot\frac{1}{T}\int_{t-T}^{t}[m(\tau)]^2d\tau = x_j^2, \tag{7}$$

so that $x_j=x_j(t)$ is simply the local rms value of s_j, taken over the last T seconds before the present time, t. It is clear that T must be short in comparison to the time required for the fading amplitude to change appreciably, but long in comparison to the period of $m(t)$.

(**C**) The noise components $n_j(t)$ are locally incoherent (*i.e.*, uncorrelated) and have zero means: $\overline{n_in_j}=\overline{n_i}\;\overline{n_j}$ if $i\neq j$, where the duration of the averages is the same as in (7). We shall also assume that the local mean square noises $\overline{n_j^2}$ are slowly varying, or, sometimes, constant.

(**D**) The local rms values of the signals, $x_j(t)=\sqrt{\langle s_j^2\rangle}$, are statistically independent. Note that this assumption automatically implies that at least two intervals are considered: first, the period T [of (7)] involved in the definition of the x_j; and second, an interval of duration T_1 in which we observe the $x_j(t)$ as new random variables. Evidently $T_1\gg T$; in practical cases, T might be a few milliseconds and T_1 approximately 30 minutes. A discussion of the requirements on T_1 is provided in Section XIII. It is important that T_1 cannot be too long. Assumption (**D**) is that, when observed in intervals with a duration on the order of T_1, the variables $x_j(t)$ are statistically independent.

The circumstances characterized by assumptions (**A**)–(**D**) are illustrated in exploded fashion in Fig. 2 for $N=2$. By "exploded," we mean that the actual signals given would be $f_j(t)=s_j(t)+n_j(t)$, $j=1, 2$, while the s_j and n_j are shown separately. The meaning of the locally coherent assumption (**B**) is that, over periods of length T, the signals s_1 and s_2 are essentially identical except in amplitude, which is approximately constant over such periods. The local rms values $x_j(t)$ are indicated by the dashed curves. Note that the assumption $s_j(t)=x_jm(t)$ implies that the $s_j(t)$ have the same zero crossings, and are in phase. If the s_j are RF or IF signals, the period T might be several microseconds or more, in which case no variation of the x_j would be perceptible within the scale of Fig. 2. If the s_j represent base-band signals, T might be a few milliseconds.

In contrast to the s_j, it will often be required that the noises $n_j(t)$ be essentially different; this is the meaning of (**C**), as suggested by the waveforms $n_1(t)$ and $n_2(t)$ of Fig. 2. In particular, it will often be assumed that $\langle n_in_j\rangle=0$ (if $i\neq j$) over every interval of length T. In addition, however, it will sometimes also be as-

[11] W. E. Morrow, Jr., C. L. Mack, Jr., B. E. Nichols, and J. Leonard, "Single-sideband techniques in UHF long-range communications," PROC. IRE, vol. 44, pp. 1854–1873; December, 1956.

sumed that the noises n_j have constant local average power, *i.e.*, that

$$\overline{n_j^2} = \frac{1}{T}\int_{t-T}^{t} [n_j(\tau)]^2 d\tau \qquad (8)$$

is a constant, independent of t and j. This would be at least approximately true of the waveforms n_1 and n_2 of Fig. 2.

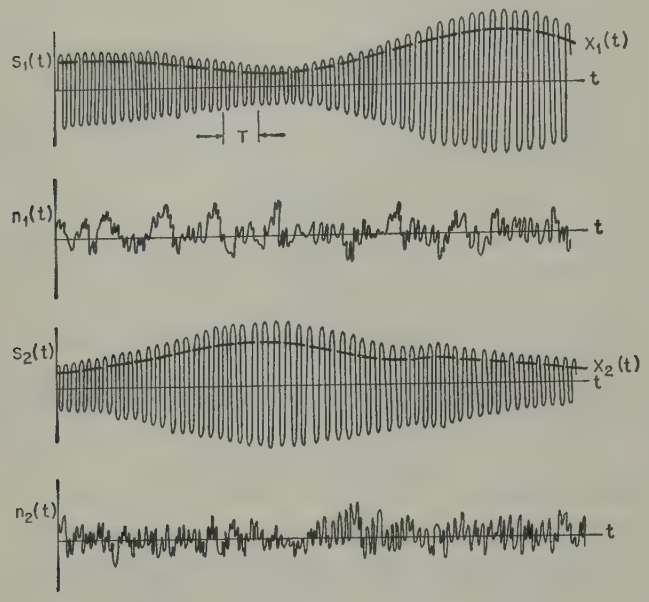

Fig. 2—Signals and noises in two diversity channels.

Assumption (**D**) is not particularly illustrated in Fig. 2, and could not be successfully illustrated there because the period T_1 required for approximate independence of the x_j is much greater than the total scale length of Fig. 2. If the x_j were plotted throughout an interval of length T_1 and the graph were then compressed to the length of Fig. 2, the resulting curves would resemble the waveforms illustrated for n_1 and n_2, except that the x_j would be non-negative and would not usually be symmetric about their mean values. In particular, the x_j are not locally coherent in the sense of (**B**), where this "locally" refers to intervals of length T_1. Note that distributions or averages of the x_j or quantities derived therefrom, *e.g.*, $\langle x_j^2 \rangle$, refer to intervals of length T_1. Such averages could be distinguished by suitable notation, *e.g.* $\langle\ \rangle_1$, but it will simplify the appearance of various expressions if the context is relied upon to make clear whether a short-term or intermediate-term average or distribution is meant.

Most of the work below is concerned with signal-noise-ratios, and from here on the word "ratio" is to mean "SNR." This will be qualified as an amplitude ratio or a power ratio as the context requires. $pj = x_j^2/\overline{n_j^2}$ will be written for the local power ratio in the jth channel, and $x_j/\sqrt{\langle n_j^2 \rangle}$, is, similarly, the local amplitude ratio. We shall often take $\overline{n_j^2} = 1$, $j = 1, 2, \cdots$, in which case the local amplitude ratio is simply x_j numerically and $p_j = x_j^2$.

It will frequently be assumed that the variables follow a Rayleigh distribution with density and distribution functions

$$p(x_j) = 2x_j e^{-x_j^2}, \qquad P(x_j) = 1 - e^{-x_j^2},$$

respectively. A plot of the Rayleigh density function given in Fig. 15. All distributions considered in th paper are zero for negative values, and expressions suc as (9) are to be understood as referring to positive valu only. Writing the Rayleigh distribution in the form (implies a particular choice of scale; in particular, it in plies that $\langle x_j^2 \rangle = 1$. The Rayleigh distribution is oft written with an arbitrary scale factor, say

$$P(y) = 1 - e^{-(y/R)^2}, \qquad p(y) = \frac{2y}{R^2} e^{-y^2/R^2},$$

in which case $\langle y^2 \rangle = R^2$. However, the data below a given in a form that is completely independent of suc scale factors, until Section XIII. This saves considerab cluttering of the landscape below. Similarly, $\overline{n_j^2} =$ will often be taken instead of $\overline{n_j^2} = n_0^2$, for exampl For, when $\overline{n_j^2} = 1$, then x_j is exactly the local amplitud ratio, which has the distribution (9), and $p_j = x_j^2$ has th simple distribution

$$G(p_j) = 1 - e^{-p_j}, \qquad g(p_j) = e^{-p_j}.$$

(Distribution functions will always be written with u per case letters, density functions with lower ca letters.)

There are four principal types of diversity combini systems in practical use. Many of the combiners actual use are not pure examples of one of these type *i.e.*, they involve approximations to, or modificatio of, one of these types. However, the effect of such mod fications can often be estimated, at least roughly. (T terminology used here is not entirely standard—indee there is no generally accepted standard terminology but is the result of careful consideration and discussi with several colleagues.) The four "pure" techniques a as follows:

1) Scanning Diversity. This technique is of t switched type; *i.e.*, at any time, only one of the a_j (6) is different from zero, and that one is equal to 1. selector device scans the channels in a fixed sequen until finding a signal above a preset threshold, uses th signal only until it drops below threshold, and th scans the other channels in the same fixed sequen until it again finds a signal above threshold. It is oft applied to the case of two antennas supplying a sing receiver through the switch, which is why it is som times called antenna selection diversity. It does not r quire a separate receiver for each channel, but at lea one of the following techniques will always outperfor it. We shall not consider this type in the present pap confining our attention to the next three. This techniq

been analyzed (for $N=2$) by Hausman [4] and most ently and most extensively by Henze [13].

) Selection Diversity. This is also a switched tech- ue, but of a more sophisticated sort. The design cri- ion here is that, at any given time, the system simply ks out the best of the N noisy signals $f_1, f_2, \cdots, f_N$, l uses that one alone; the others do not then contrib- to $f(t)$. More precisely, let k denote the index of a nnel for which $p_k \geq p_j$, $j=1, 2, \cdots, N$; then this e of system is characterized by the design criterion

$$a_j = \begin{cases} 1, & \text{for } j = k, \\ 0, & \text{for } j \neq k, \end{cases} \tag{12}$$

terms of (6). This is essentially the classical form of ersity communication [1], [2]. Very often, the selec- n in such systems is by electronic means (*e.g.*, by ng a common detector in such a way that the strong- signal cuts the others off) and is not quite as sharp as 2) would indicate; however, (12) is often a good proximation to such cases. A three-channel selection versity system is depicted in Fig. 3.

3) Maximal-Ratio Diversity. This system is defined the property that, among all systems of the type (6), yields the maximum SNR of the output signal $f(t)$, ovided assumptions (**A**), (**B**), and (**C**) are satisfied. ore precisely, let p denote the local power ratio of). Then a maximal-ratio system realizes

$$p = \sum_{j=1}^{N} p_j; \tag{13}$$

., the maximum power ratio realizable from any linear mbination (6) is equal to the sum of the individual wer ratios. Furthermore, the result (13) is equivalent the requirement that the coefficients in (6) be propor- nal to

$$a_j = x_j / \overline{n_j^2}; \tag{14}$$

., the maximum output ratio (13) is realized if and ly if the gain of each channel is proportional to the s signal and inversely proportional to the mean uare noise in that channel, with the same propor- nality constant for all channels. This will be proven low.

(This result has several times been quoted in the erature as requiring the weighting to be proportional the amplitude ratio. It should be noted that this is rrect only in the case where the local noise powers are equal, in which case it would be less misleading to eak of weighting proportional to the rms signal.)

It is clear that (13) is a definite improvement over her scanning diversity or selection diversity, which n yield only one of the terms in the sum $\sum p_j$ as the tput power ratio. This observation is essentially due Kahn [5], although the form stated here can be traced [6], and closely similar results have been used in lar systems for some time. (It is quite possible that diversity system discussed by Peterson, *et al.* [2] was actually a maximal-ratio system. However, the authors made it clear that they were thinking in terms of selection diversity, whatever their actual instrumentation may have realized.) Maximal-ratio diversity has sometimes been called ratio squarer diversity, optimum diversity, and combiner diversity. Radar systems of the type discussed in connection with (4) and which employ square-law detection are essentially maximal-ratio systems. The general arrangement of a two-channel maximal-ratio system suitable for postdetection combining is shown in Fig. 4; a predetection combiner would require the addition of phase-control circuitry to satisfy assumption (**B**).

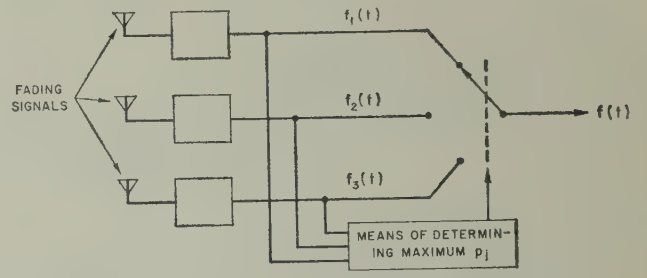

Fig. 3—Selection diversity. The f_j may be predetection or postdetection signals.

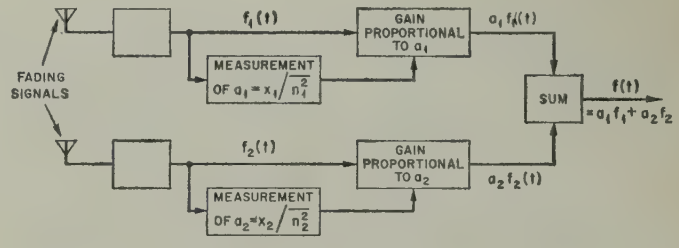

Fig. 4—Maximal-ratio diversity.

4) Equal-Gain Diversity. This is probably the simplest possible linear diversity technique; it is characterized by the property that all channels have exactly the same gain. Thus, in terms of (6),

$$a_j = 1, j = 1, 2, \cdots, N, \tag{15}$$

i.e., the noisy signals $f_j(t)$ are simply added together. In applications of this technique, the channel gains can be made to vary in such a way that the resultant signal level is approximately constant; however, this is irrelevant to the performance of the system. The important feature is that the channel gains are all equal. Note: it is important to observe that this is not the case with conventional common-detector type diversity systems; a common-detector combiner is essentially a selection diversity system, and an equal-gain system is decidedly different both in instrumentation and performance. However, an equal-gain system may well use a common AGC detector, but not a common signal detector of the usual type, as is also the case with maximal-ratio sys-

tems [5]. A basic two-channel equal-gain system is illustrated in Fig. 5. Note that the blank boxes representing receivers must have the same gains, including conversion and detection gains, which, therefore, must be fixed; they could not include separate, independent AGC systems. Also, they could not be conventional FM (or similar) receivers, as the detection gain of an FM receiver depends on the signal level. However, it is possible to instrument unconventional FM detectors for postdetection equal-gain combining.[12] An arrangement suitable for use with AGC is shown in Fig. 6. As in the case of Fig. 4, the application of an equal-gain combiner before detection would require the addition of phase control provisions to Figs. 5 and 6.

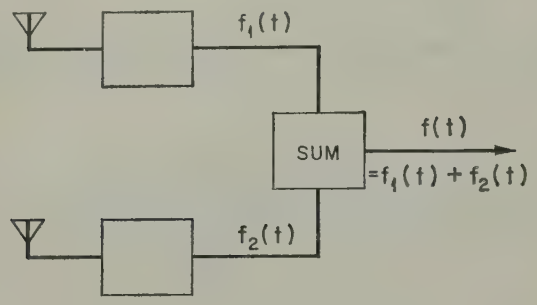

Fig. 5—Basic equal-gain diversity.

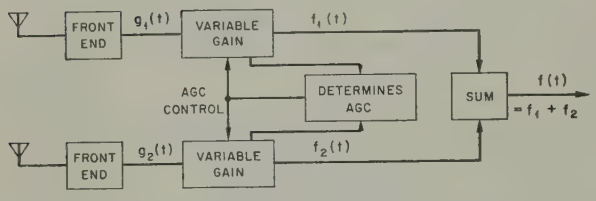

Fig. 6—Equal-gain diversity. The boxes "variable gain" must have the same gain, which may include conversion and detection gain.

It has been pointed out by Sichak [8][13] that, under conditions often occurring in practice, equal-gain systems will outperform selection diversity, and will perform almost as well as maximal-ratio systems. In view of the simplicity of the instrumentation required for (15) as compared to (14) (equivalently, see Figs. 5 and 4), this fact is of great practical importance. The conditions required are that assumptions (**A**)–(**D**) must be satisfied; in addition, the x_j must be Rayleigh-distributed, and the local mean square noises $\overline{n_j^2}$ must be approximately constant. Under other conditions, it may not perform as well as selection diversity, as will be seen. Since, however, these conditions are often (approximately) satisfied, it follows that equal-gain diversity should be more widely known than is presently the case.

In the following three sections, the principal features of diversity combiners of types 2)–4) above will be developed. In particular, distribution functions will be ob tained for the local power ratio p of the composit signal $f(t)$, and mean values of p, under the condition discussed. Then, in Sections VII to XII the results wi be compared and evaluated, and the way in which th results are altered by various modifications of the con ditions as they occur in practice will be indicated.

III. Selection Diversity

The distribution function for an N-channel selectio diversity system is particularly simple to obtain, pro vided the local noise powers $\overline{n_j^2}$ are constant. L $\overline{n_j^2}=1$, $j=1, 2, \cdots, N$, and assume that the x_j a Rayleigh-distributed. Then the individual chann power ratios p_j have the distribution $G(p_j)$ of (11). B (12), the output power ratio of the combiner is simpl the largest of the individual p_j. Now, if the largest powe ratio is $\leq p$, then the power ratio of every channel $\leq p$; conversely, if the power ratio of every channel $\leq p$, then so is the power ratio of f. Hence, the probabi ity of having the power ratio of f be $\leq p$ is precisely th probability of having the individual channel ratios a $\leq p$ simultaneously. Since the x_j are independent, b (**D**), so are the $p_j=x_j^2$, and, hence, the probability tha all channels have power ratio $\leq p$ is simply the produc of the separate probabilities that each channel indivi ually has a power ratio $\leq p$. Thus,

$$S_N(p) = G(p)\cdot G(p)\cdot\cdots G(p) = [G(p)]^N \qquad (1$$
$$= (1 - e^{-p})^N$$

is the distribution function of p, the realized local pow ratio, for an N-order selection diversity system.

The average value $\bar{p}$ of p will be required for th system. In this case, it is most easily obtained from th distribution (16). Thus,

$$\bar{p}(N) = \int_{-\infty}^{\infty} p\,dS_N(p) = \int_0^{\infty} pN(1 - e^{-p})^{N-1}e^{-p}dp. \qquad (1$$

This integral is evaluated in Appendix VI, where it shown to reduce to the remarkably simple form

$$\bar{p}(N) = \sum_{k=1}^{N} \frac{1}{k}. \qquad (1$$

Thus, $\bar{p}(2)=1+\frac{1}{2}=\frac{3}{2}$, $\bar{p}(3)=1+(\frac{1}{2})+(\frac{1}{3})=11/6$, et these values will be used below. It is clear at once fro (18) that increasing the number of channels in a sele tion diversity system yields rapidly diminishing return adding the Nth channel increases $\bar{p}$ by only $1/N$. It w be seen that the next two systems to be considered c perform much better in this respect, in consequence (**B**) and (**C**). However, it should be noted here th neither the functioning of a selection diversity syste nor the statistics developed in this section depend assumptions (**B**) or (**C**), which are not required here. T significance of this fact will be discussed.

[12] R. T. Adams, private communication; December, 1958.
[13] W. Sichak, Fed. Telecommun. Labs., Nutley, N. J., private communication; August 19, 1955.

IV. Maximal-Ratio Diversity

he first order of business is to establish (13) and (14). order to do this, it will be convenient to use a hematical device known as the Schwarz inequality. s is not specifically related to statistics, but is a gen- result of great importance in many fields of pure applied mathematics. One form of this states that $u_1, u_2, \cdots, u_N$ are any N real numbers and $v_1, v_2, \cdots, v_N$ are any N real numbers, then

$$\left[\sum_{j=1}^{N} u_j v_j\right]^2 \leq \left[\sum_{j=1}^{N} u_j^2\right]\left[\sum_{j=1}^{N} v_j^2\right]. \tag{19}$$

e proof of this, which is quite short, is given in Ap- dix II. Note that if $u_j = a_j\sqrt{\langle n_j^2\rangle}$, $v_j = x_j/\sqrt{\langle n_j^2\rangle}$, n (19) takes the form

$$\left[\sum_{j=1}^{N} a_j x_j\right]^2 \leq \left[\sum_{j=1}^{N} a_j^2\overline{n_j^2}\right]\left[\sum_{j=1}^{N} (x_j^2/\overline{n_j^2})\right], \tag{20}$$

ich, since $p_j = x_j^2/\overline{n_j^2}$, can be written

$$\left[\sum_{j=1}^{N} a_j x_j\right]^2 \leq \left[\sum_{j=1}^{N} a_j^2\overline{n_j^2}\right]\left[\sum_{j=1}^{N} p_j\right]. \tag{21}$$

Now, in (6), let us write

$$s(t) = \sum_{j=1}^{N} a_j s_j(t), \qquad n(t) = \sum_{j=1}^{N} a_j n_j(t), \tag{22}$$

that $f(t) = s(t) + n(t)$, and $p = \overline{s^2}/\overline{n^2}$ is the local power io of f. But (all sums from 1 to N)

$$\overline{s^2} = \langle[\sum a_j s_j]^2\rangle$$

d by assumption (**B**)

$$= \langle m^2[\sum a_j x_j]^2\rangle$$
$$= \langle m^2\rangle \cdot [\sum a_j x_j]^2$$

d since $[\sum a_j x_j]^2$ is locally constant and can be taken tside the average, and since $\overline{m^2} = 1$,

$$\overline{s^2} = [\sum a_j x_j]^2. \tag{23}$$

Furthermore,

$$\overline{n^2} = \langle[\sum a_j n_j]^2\rangle$$
$$= \sum a_j^2\overline{n_j^2}, \tag{24}$$

(61) and assumption (**C**). Thus, using (21),

$$p = \frac{\langle s^2\rangle}{\langle n^2\rangle} = \frac{[\sum a_j x_j]^2}{\sum a_j^2\overline{n_j^2}} \leq \sum p_j, \tag{25}$$

ich proves that p cannot exceed $\sum p_j$. On the other nd, if $a_j = x_j/\overline{n_j^2}$, then

$$p = \frac{[\sum x_j^2/\overline{n_j^2}]^2}{\sum x_j^2/\overline{n_j^2}} = \frac{[\sum p_j]^2}{\sum p_j}$$
$$= \sum p_j, \tag{26}$$

that $p = \sum p_j$ if $a_j = x_j/\overline{n_j^2}$, and similarly if $a_j = k(x_j/\overline{n_j^2})$ for any $k \neq 0$, thus proving (13) and (14). [Readers acquainted with the Schwarz inequality for complex numbers will recognize that it may be used to include the case of positive or negative x_j, or even complex x_j. This is, however, only a more formal way of including assumption (**B**).]

It is interesting to note that the only purely statistical fact used in this development is that averaging is a linear operation, as discussed in Appendix I. No use was made of distribution functions or any similar apparatus. However, it is important to observe that each of the assumptions (**A**)–(**C**) entered in a very vital way.

We now consider the statistical properties of the local power ratio p. The first point to be noticed is that $p = \sum p_j$ implies

$$\bar{p} = \sum_{j=1}^{N} \bar{p}_j, \tag{27}$$

without regard to the distribution of the p_j or the possible dependence of these variables. If, in particular, $\bar{p}_j = 1$, $j = 1, 2, \cdots, N$, then

$$\bar{p}(N) = N. \tag{28}$$

This behavior is in marked contrast to the corresponding relationship (18) for selection diversity, which increases much less rapidly with N than (28) does.[14] (It should be clear that the notation $\bar{p}(N)$ is used in a somewhat flexible way; $\bar{p}(N)$ is a different function of N in (18) than it is here.) The average value of the local power ratio of the output of an N-order maximal-ratio system is simply 10 $\log_{10} N$ db above a single channel.

In order to obtain an explicit distribution of p, we shall employ the same assumptions used for the selection diversity case, namely, that the x_j are independent Rayleigh variables and that $\overline{n_j^2} = 1$, $j = 1, 2, \cdots, N$, so that the p_j have the exponential distribution (11). Thus we are interested in the distribution of the sum $p = \sum p_j$ of N independent random variables, each with the distribution (11). This problem can be treated by a simple application of characteristic functions,[2] as indicated in Appendix III. Alternatively, it can easily be solved by using the geometric approach mentioned in Appendix I, without reference to characteristic functions. (One integrates the joint density function

$$\exp\left[-(p_1 + p_2 + \cdots + p_N)\right]$$

over the N-dimensional volume bounded by the hyperplane $p_1 + p_2 + \cdots + p_N = p$ and the coordinate hyperplanes.) In either case, the result, writing $G_N(p)$ for the desired distribution function and $g_N(p)$ for the associated density function, is

$$g_N(p) = \frac{1}{(N-1)!}\, p^{N-1}e^{-p}, \tag{29}$$

$$G_N(p) = \frac{1}{(N-1)!}\int_0^p y^{N-1}e^{-y}dy. \tag{30}$$

[14] For large N, (18) is approximately $\log_e N$.

By using $G_1(p)=1-e^{-p}$ and the recursion relation $G_N(p)=G_{N-1}(p)-g_N(p)$, easily verified by an integration by parts, we have

$$G_2(p) = 1 - (1+p)e^{-p},$$

$$G_3(p) = 1 - \left(1+p+\frac{p^2}{2'}\right)e^{-p},$$

$$G_4(p) = 1 - \left(1+p+\frac{p^2}{2!}+\frac{p^3}{3!}\right)e^{-p},$$

and, in general,

$$G_N(p) = 1 - \left(\sum_{k=0}^{N-1}\frac{p^k}{k!}\right)e^{-p}, \tag{31}$$

which can also be written

$$G_N(p) = \left(\sum_{k=N}^{\infty}\frac{p^k}{k!}\right)e^{-p}. \tag{32}$$

The utility of the form (32) is that it indicates the approximations

$$G_N(p) \cong \frac{p^N}{N!}e^{-p} \cong \frac{p^N}{N!} \tag{33}$$

are accurate for sufficiently small p. The distribution (31), known as the gamma distribution, is easily computed for the integral values of N of interest here and has also been tabulated.[15] It can also be identified with the chi-square distribution with $2N$ degrees of freedom.[16]

The origin of the maximal-ratio distribution (31) has sometimes been incorrectly attributed (in Pierce [15] and Packard [14] among others). That (31) is the distribution function of sums of squares of Rayleigh variables has been known in radar circles for quite some time. In the context of maximal-ratio diversity combiners, the result (31) for arbitrary N was first published in March, 1956, by Altman and Sichak.[17] (It also appeared independently in an unpublished memorandum[1] at about the same time.) Curves of (31) for several values of N were subsequently published by Staras [9].

V. Equal-Gain Diversity

Recalling that the relations $\overline{s^2}=[\sum a_j x_j]^2$ of (23) and $\overline{n^2}=\sum a_j^2\overline{n_j^2}$ of (24) did not depend on a choice of the a_j [*i.e.*, they hold for any combiner of the type (6), provided assumptions (**A**)–(**C**) are satisfied, and hence hold in particular for $a_j=1$, $j=1, 2, \cdots, N$], we have

$$\overline{s^2} = \left[\sum_{j=1}^{N} x_j\right]^2 \tag{34}$$

and

$$\overline{n^2} = \sum_{j=1}^{n}\overline{n_j^2} \tag{35}$$

for an equal-gain system. The relation $\sqrt{\langle s^2\rangle}=\Sigma x_j$ from (34) is simply the well-known fact that the rms value of a sum of coherent signals is equal to the sum of the individual rms values, while (35) similarly expresses the fact that the average power of a sum of uncorrelated signals is equal to the sum of the individual average powers. Some communication engineers express (34) by saying that coherent signals "add linearly"; however, this language is both formally meaningless and conducive of an imperfect understanding of the situation and is better replaced by "add coherently" if some such expression is necessary.

From (34) and (35), we have

$$\phi = \frac{[\sum x_j]^2}{\sum \overline{n_j^2}} \tag{36}$$

for an equal-gain system. In order to develop comparative statistics for this, it is again assumed that $\overline{n_j^2}=1, j=1, 2, \cdots, N$, and that the x_j are independent and Rayleigh-distributed. Since $\overline{n_j^2}=1$, $p=[\sum x_j]^2/N$. Put

$$u = \sqrt{N\phi} = \sum_{j=1}^{N} x_j. \tag{37}$$

It is clear that the distribution function of p will follow immediately from that for u. The distribution of a sum of N Rayleigh variables, each with the distribution (9), is accordingly of interest. Unfortunately, this problem is not nearly as tractable as in the maximal-ratio case. The characteristic function of a Rayleigh variable is not expressible in an immediately useful form. We are here essentially forced to rely on the geometric approach mentioned in Appendix I. Let $B_N(u)$ denote the distribution function of (37). For $N=2$, say $u=x+y$, it can be seen that $B_2(u)$ is given by the integral of the joint density function $4xye^{-(x^2+y^2)}$ over the region of the $x-y$ plane bounded by the line $x+y=u$ and the coordinate axes (Fig. 7). (We can stay in the first quadrant because the density function is zero in all other quadrants.) It is easy to see that this is

$$B_2(u) = \int_0^u \int_{x=0}^{x=u-y} 4xye^{-(x^2+y^2)}dxdy$$

$$= 2\int_0^u ye^{-y^2}[1-e^{-(u-y)^2}]dy. \tag{38}$$

[15] K. Pearson (ed.), "Tables of the Incomplete Γ Function," Cambridge University Press, Cambridge, Eng.; 1946. In his notation, he tabulates

$$I(u,p) = \frac{1}{p!}\int_0^{u\sqrt{p+1}} t^p e^{-t}dt,$$

so that his p is here $N-1$, and his u is here $p/\sqrt{N}$.

[16] E. S. Pearson and H. O. Hartley (eds.), "Biometrika Tables for Statisticians," Cambridge University Press, Cambridge, Eng., Table 7, p. 122 ff.; 1954. Short tables of the χ^2 distribution are given in many other statistical tables and in most textbooks on statistics. See, for example, H. Cramér, "Mathematical Methods of Statistics," Princeton University Press, Princeton, N. J.; 1946.

[17] Altman and Sichak, [8], p. 55, middle of right-hand column, with $(aL)^2=p$.

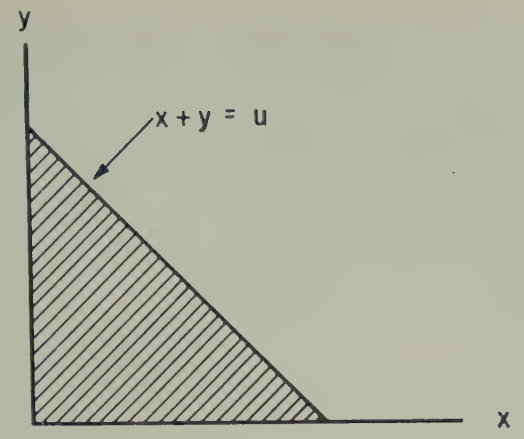

Fig. 7—Region of integration for (38).

By completing the square in the exponent and making a few other routine manipulations, this becomes [8]

$$B_2(u) = 1 - e^{-u^2} - (\sqrt{\pi/2})ue^{-u^2/2}H\left(\frac{u}{\sqrt{2}}\right), \quad (39)$$

where

$$H(x) = \frac{2}{\sqrt{\pi}}\int_0^x e^{-t^2}dt$$

is the error function and is tabulated.[18] Thus the distribution function of $p=u^2/2$, $A_2(p)$, is $B_2(\sqrt{2p})$, *i.e.*,

$$A_2(p) = 1 - e^{-2p} - \sqrt{\pi}pe^{-p}H(\sqrt{p}), \quad (40)$$

and is readily plotted.

Corresponding to (38), it is easy to see that the distribution function of the sum of N independent Rayleigh variables is

$$B_N(u) = 2^N \int_0^u \int_0^{u-x_N} \cdots \int_0^{u-\sum_{k=3}^N x_k} \int_0^{u-\sum_{k=2}^N x_k} x_1x_2 \cdots x_N\, e^{-(x_1^2+\cdots+x_N^2)}dx_1 \cdots dx_N, \quad (41)$$

which is simply the integral of the joint density function over the N-dimensional volume bounded by the hyperplane $x_1+x_2+\cdots+x_N=u$ and the coordinate hyperplanes, as in Fig. 7 for $N=2$. Unfortunately, the integral (41) is quite as frightful as it appears; numerous workers—going back to Lord Rayleigh himself—have tried to express $B_N(u)$ in terms of tabulated functions, but with no success if $N\geq 3$. However, $B_N(u)$ has recently been tabulated,[19] and curves of $A_N(p)=B_N(\sqrt{Np})$ have been constructed from these tables for the present paper (in Section VI) for $N=2$, 3, 4, 6, and 8. An outline of the method of computation is sketched in Appendix IV.

We shall next obtain the average values $\bar{p}(N)$ for the equal-gain case. Although these averages depend on the distribution of p and the distribution of p is not given in a particularly explicit form, it is nevertheless easy, following Appendix I, to obtain the $\bar{p}(N)$. Since $\overline{n_j^2}=1$, (36) becomes

$$p = \frac{1}{N}\left[\sum_{j=1}^N x_j\right]^2 = \frac{1}{N}\left[\sum_{j=1}^N x_j^2 + \sum_{i\neq j} x_ix_j\right]. \quad (42)$$

Since the x_j are independent, $\overline{x_ix_j}=\bar{x}_i\bar{x}_j$ if $i\neq j$, so

$$\bar{p} = \frac{1}{N}\left[\sum_{j=1}^N \overline{x_j^2} + \sum_{i\neq j}\bar{x}_i\bar{x}_j\right] = 1 + \frac{1}{N}\sum_{i\neq j}\bar{x}_i\bar{x}_j, \quad (43)$$

using the fact that $\overline{x_j^2}=1$, $j=1, 2, \cdots, N$. Let $\bar{x}_j=r$, $j=1, 2, \cdots, N$. By considering the terms of the sum $\sum_{i\neq j}\bar{x}_i\bar{x}_j$ as the entries from an N by N matrix with the main diagonal deleted, it is seen that there are $N^2-N=N(N-1)$ such terms, each equal to r^2, and so

$$\bar{p}(N) = 1 + (N-1)r^2, \quad (44)$$

the desired average value. The constant $r^2=(\bar{x}_j)^2$ depends on the distribution of the x_j. For the Rayleigh distribution, $r^2=\pi/4\cong 0.785$. For any distribution, $r^2=(\bar{x})^2/\overline{x^2}$ is a dimensionless constant between 0 and 1, but values of r^2 much less than 0.785 are relatively infrequent in observed fading distributions.

It is thus seen that $\bar{p}$ increases linearly with N, as was also the case for maximal-ratio systems. The only difference is that (28) increases with slope 1 while (44) increases with slope $r^2=\pi/4$ for Rayleigh fading. But the absolute maximum by which (28) can exceed (44) is 10 $\log_{10}(4/\pi)=1.05$ db, and this only in the limit of an infinite number of channels.

VI. Canonical One-Hour Performance

The three systems will first be compared simply on the basis of the average values of the local power ratio p of the output. This is done first in Fig. 8, for $N=1$, 2, 3, $\cdots$, 10 channels. The maximal-ratio points are values of 10 $\log_{10} N$ from (28), the equal-gain points are 10 $\log_{10}[1+(N-1)(\pi/4)]$ from (44), and the selection diversity values are

$$10\log_{10}\left[\sum_{k=1}^N (1/k)\right]$$

from (18). Since $\bar{p}_j=1$, these give the increase in decibels in the average local power ratio over a single channel. The data of Fig. 8 for $N=2$, 3, 4, 6, and 8 are presented from a different point of view in Table I, which gives

[18] "Tables of the Error Function and its Derivative," Natl. Bur. Stand., Washington, D. C., Appl. Math. Ser. No. 41; 1954. The error function or, for that matter, (39) itself, can also be expressed in terms of the much tabulated normal (Gaussian) probability distribution function. See "Tables of the Normal Probability Functions," Natl. Bur. Stand., Appl. Math. Ser. No. 23; 1953. Brief tables of the normal distribution function appear in most statistical texts, *e.g.*, Cramér, *op. cit.*

[19] W. C. Mason, M. Ginsburg, and D. G. Brennan, "Tables of the distribution functions of sums of Rayleigh variables," to be published.

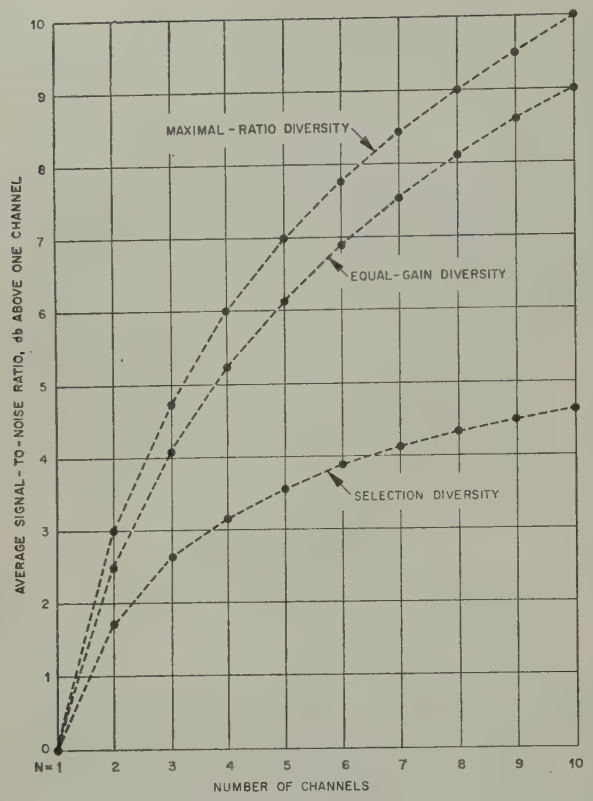

Fig. 8—Diversity improvement (in decibels) in average SNR, for independently fading Rayleigh-distributed locally coherent signals in locally incoherent noises with constant local rms values.

TABLE I

COMPARATIVE AVERAGE SNR (SAME CONDITIONS AS IN FIG. 8)

Number of Channels N	Number of DB by which Maximal-Ratio Exceeds		
	Equal-Gain	Selection	One Channel
2	0.49	1.25	3.01
3	0.67	2.14	4.77
4	0.76	2.83	6.02
6	0.85	3.89	7.78
8	0.90	4.69	9.03
.	.	.	.
.	.	.	.
.	.	.	.
∞	1.05	∞	∞

the differences between the maximal-ratio values and the lower curves of Fig. 8, counting the zero axis as a curve. The last entry in the equal-gain column is essentially the assertion that no matter how far the curves of Fig. 8 were continued, the top two would never differ by more than 1.05 db, although they would get farther and farther away from the selection diversity curve and the base axis.

A brief discussion of the significance of these data is in order. These results are useful, for example, in estimating relative average system capacities, or in other circumstances where the average value alone of p is of interest. Most recent diversity systems have been designed for a specified percentage of reliability, *i.e.*, a

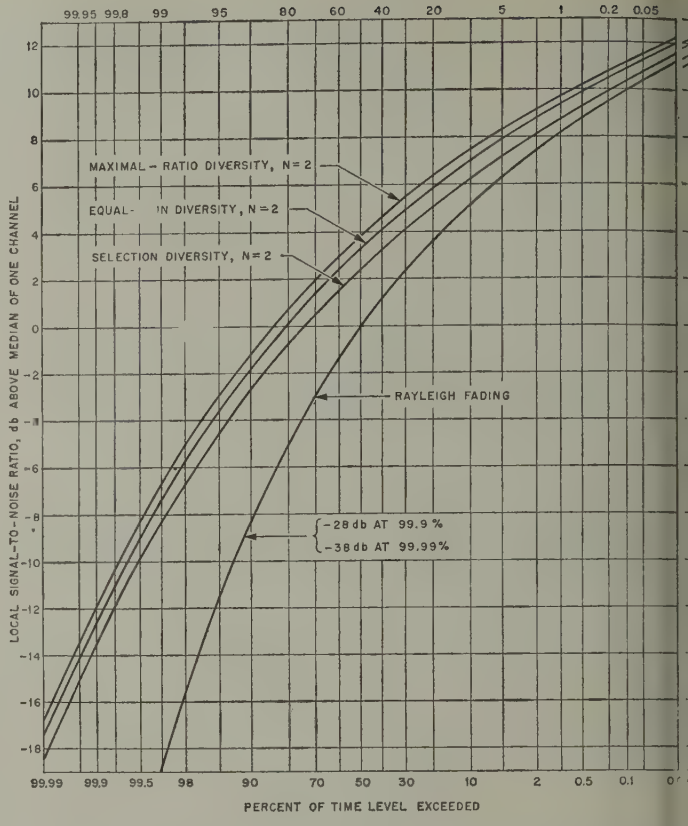

Fig. 9—Dual diversity distributions, conditions of Fig. 8.

specified percentage of time during which the system performance will exceed some given criterion. This requires information about probability distributions. This approach is appropriate whenever high reliability is a primary requisite, *e.g.*, in important military communication systems, or in relay systems carrying commercial television programs. However, it should be pointed out here that some systems do not require very high local reliability or they may effectively achieve it by other means, such as coding. In such circumstances, the data of Table I may be more meaningful than results based on the distributions to be presented.

Let us next compare the probability distributions of p realized by the three systems for different orders of diversity. The case $N=2$ (dual diversity) is illustrated in Fig. 9, together with the distribution of p for a single channel with Rayleigh fading for comparison. The term "median" in the designation of the ordinate scale of Fig. 9 refers to a value x_0 of a random variable x for which $P(x_0)=\frac{1}{2}$, *i.e.*, a value x_0 for which $x \leq x_0$ for 50 per cent of the time and $x \geq x_0$ for 50 per cent of the time. Thus, the median p_0 of the one-channel distribution (11) is obtained by setting $G(p_0)=\frac{1}{2}$ and solving for p_0, from which $p_0=\log_e 2 \cong 0.693$. The ordinate scale of Fig. 9 is expressed in decibels relative to this p_0. That is, the $N=2$ curves of Fig. 9 are plots of $10 \log_{10}(p/p_0)$ vs $100\ [1-D_2(p)]$, where $D_2(p)$ is, respectively, $G_2(p)$ of (31) (maximal-ratio), $A_2(p)$ of (40) (equal-gain) and

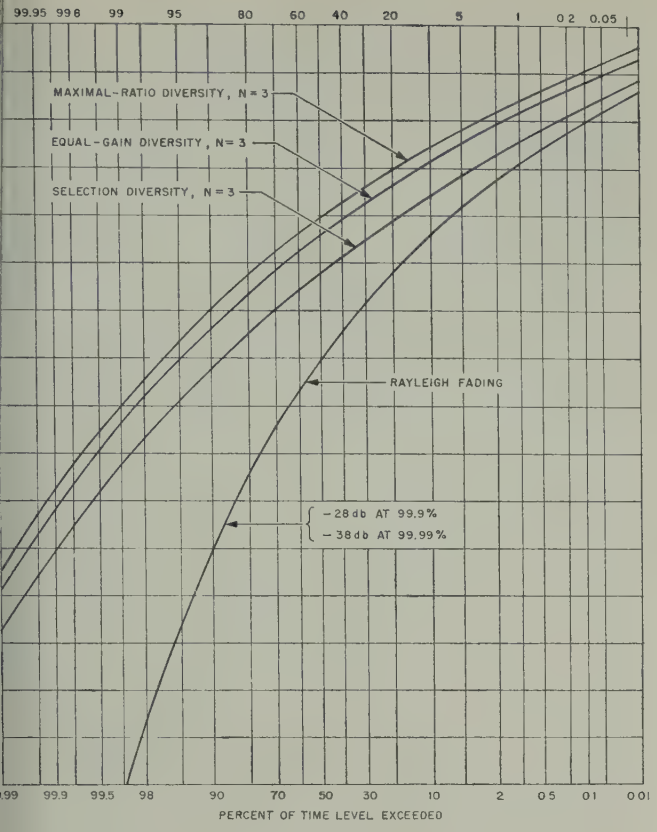

Fig. 10—$N=3$.

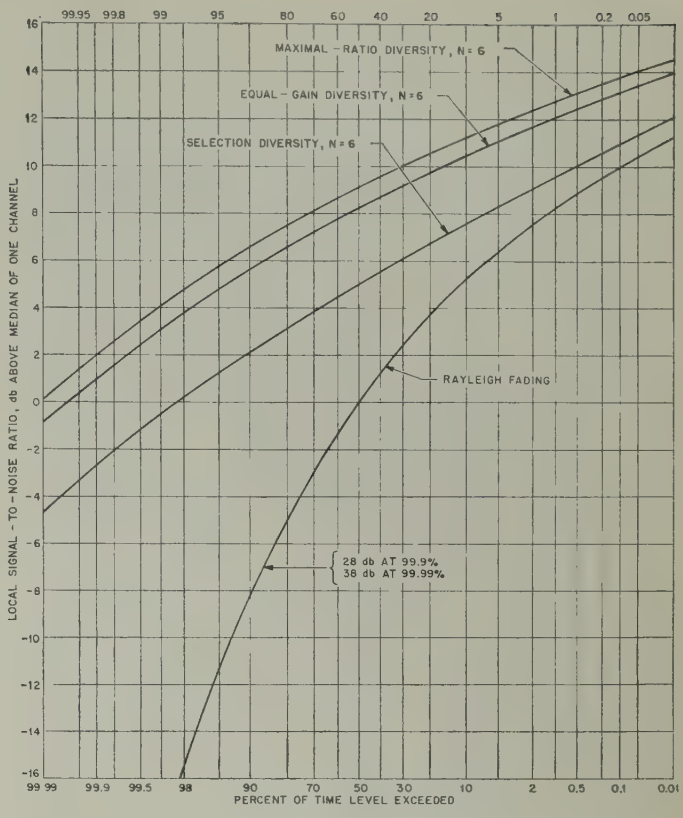

Fig. 12—$N=6$.

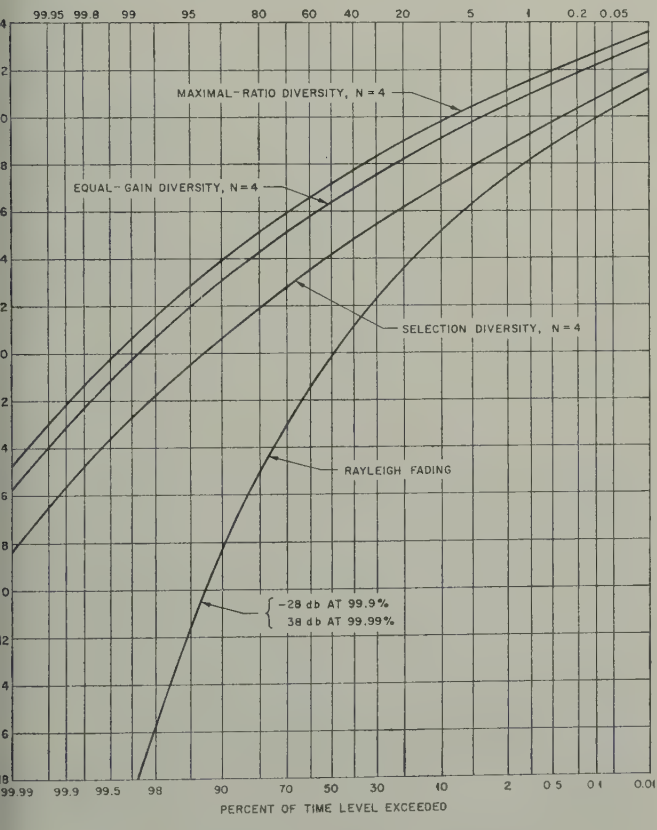

Fig. 11—$N=4$.

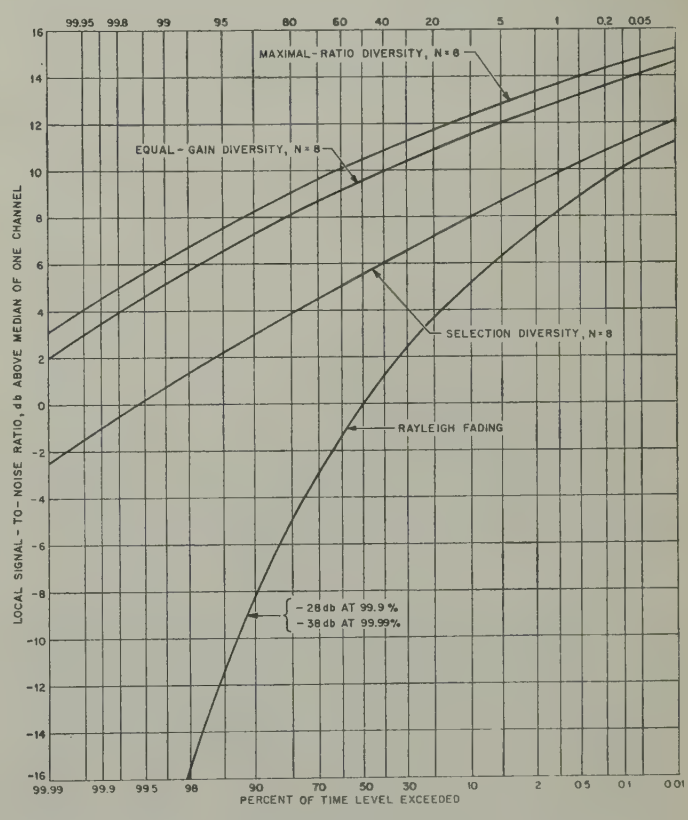

Fig. 13—$N=8$.

$S_2(p)$ of (16) (selection). $100\ [1-D_2(p)]$ is the per cent of time ordinate exceeded. The Rayleigh fading curve is $100\ [1-G(p)]$ of (11). (For the distributions considered here, the median values of p do not differ from the corresponding mean values by more than about 1.6 db. The reason for using the median value of the Rayleigh distribution as a reference here is that this is commonly presented as an experimental datum, since median values can be read directly from the distribution function determined by a totalizer.)

It is clear that the differences between the various dual diversity curves of Fig. 9 are quite small, especially in comparison to the difference between any one of them and the Rayleigh fading curve. For example, the 99.99 per cent exceeded level of the selection diversity curve is almost 20 db above the Rayleigh curve, while the maximal-ratio curve is only 1.4 db above the selection curve at the 99.99 per cent point. Evidently one would choose among the three types of two-channel systems on the basis of Fig. 9 only if one were fighting for the last decibel. Even then, one would wish to make very sure that that last decibel could actually be realized, the selection diversity curve does not depend on the important assumptions (**B**) and (**C**), which must be satisfied for the equal-gain and maximal-ratio systems to work properly, as will be seen.

However, the differences in the performance of the various combining techniques become more important as the number N of channels is increased. The maximal-ratio and equal-gain systems improve much more rapidly than selection diversity does, as can be seen in Figs. 10–13, which give the distributions for $N=3$, 4, 6, and 8, respectively.[20] (Note that the ordinate scales of Figs. 9–13 cover different ranges.) However, the maximal-ratio and equal-gain curves remain quite close together; indeed, the difference between them is hardly significant even for $N=8$. This is one of the facts that makes equal-gain diversity quite attractive and suggests that there are many applications where it should be exploited. It can be seen that the maximal-ratio and equal-gain curves differ approximately by the constants in the equal-gain column of Table I; that is, the equal-gain diversity distributions can be approximated quite well by translating the maximal-ratio distributions downward by the values in the second column of Table I.

The data of Figs. 9–13 are useful in the design of radio communication systems and radar and navigation systems of the type discussed in the Introduction. One such application is as follows. Suppose a high-reliability communication system is to be designed for a fixed information rate, which cannot be maintained whenever the received local power ratio p drops below a certain value. That is, it is desired to maintain the local power ratio above a certain value for, say, 99 per cent of the time during an interval of length T_1, for which the curves of Figs. 9–13 are applicable if the relevant conditions are satisfied. Referring to the 99 per cent exceeded values of Fig. 9, it can be seen that the difference between the Rayleigh fading curve and the dual selection diversity curve is about 10 db at the 99 per cent point. But this implies that whatever transmitter power was required for a single-channel system, a transmitter of 10 db less power would be adequate if dual selection diversity were employed at the receiving terminal. Of course, part of the reduction could be applied to the antenna gains, etc. Similarly, reference to the 99 per cent values of Fig. 11 shows that the use of fourth-order maximal-ratio diversity would enable a reduction in transmitter power of 19 db relative to that required for a single-channel system.

This reduction in transmitter power required for a given grade of local reliability has been called "diversity gain." The term was apparently introduced by Jelonek *et al.* [3]. Here the term "local reliability diversity gain," or simply "local reliability gain," is used to emphasize the fact that it is not a gain in the usual sense and that it depends very heavily on the local reliability percentage chosen. The dependence of the local reliability gains on the percentage selected can be seen in Table II which gives the values realized by the three types of systems for $N=2$, 3, 4, 6, and 8 corresponding to local reliability percentages of 99 per cent and 99.9 per cent.

TABLE II

LOCAL RELIABILITY GAINS (IN DB), CONDITIONS OF FIG. 8, FOR 99 PER CENT AND 99.9 PER CENT LOCAL RELIABILITY

N	Selection		Equal-Gain		Maximal-Ratio	
	99 per cent	99.9 per cent	99 per cent	99.9 per cent	99 per cent	99.9 per cent
2	10	14.5	11	15.5	12	16
3	14	20	16	21.5	16.5	22.5
4	16	22.5	18.5	25	19.5	26
6	18	25.5	21.5	29	22.5	30
8	19	27	23.5	31.5	24.5	32.5

It can be seen that the values of Table II are much larger than those of Fig. 8. They can be made to appear even larger by computing the local reliability gains corresponding to 99.99 per cent or higher percentages; however, considering the present or immediately foreseeable state of the art, such values would not be meaningful. Among other things, the Rayleigh distribution does not provide an accurate model for actual fading distributions outside of the 0.1 per cent to 99.9 per cent range.

Various modifications and extensions of these considerations as they occur in practice will be considered next. However, it should be noted that there are many practical situations in which the conditions assumed above are realistic approximations, and for which the results can be used without significant modifications.

[20] High-resolution graphs of the curves of Figs. 9–13 are available from the author to those having serious need of such graphs. Letters requesting the same should describe the nature of said need. Requests on postal cards or form letters will not be honored. This offer may be withdrawn at any time.

VII. Non-Rayleigh Fading Distributions

Only in the case of long-range UHF and SHF tropospheric transmission does it appear that observed fading distributions are most often Rayleigh, when observed intervals of length T_1. For short-range UHF circuits and normal or scatter ionospheric transmission at HF and below, other distributions are often observed. Indeed, at frequencies of a few megacycles and below, a accurate fit to the Rayleigh distribution is more rarly the exception than the rule. It is therefore of interest to discuss the way in which these results are modified by other distributions, assuming that the other onditions still hold.

Certain of these results are easily discussed. The aximal-ratio curve of Fig. 8 and the last column of able I do not in any way depend on the fading distriution and are not modified at all. In order to discuss ie effect on the distributions of Figs. 9–13, it will be onvenient to return to the geometric approach menoned in Appendix I and consider the case $N=2$ chanels. Let $x=x_1$ and $y=x_2$ be the local amplitude ratios the two channels. The probability that a maximalatio system has a local power ratio $\leq p$, *i.e.*, the maxial-ratio distribution function $G_2(p)$, is obtained by tegrating the joint density function of x and y over ie interior of the quarter circle $x^2+y^2=p$ in the $x-y$ lane. Similarly, the equal-gain distribution function $_2(p)$ is obtained by integrating the same density funcon over the triangle bounded by the line $x+y=\sqrt{2p}$. he corresponding region for the selection diversity disibution $S_2(p)$ is the square bounded by $x=\sqrt{p}$, $=\sqrt{p}$. These three regions are shown together in Fig. 4. Now, the fact that the maximal-ratio system outerforms the other two is intimately connected with the act that, for any fixed p, the probability that the maxial-ratio output ratio is $\leq p$ is smaller than it is for the thers, that is, $G_2(p)<A_2(p)$ and $G_2(p)<S_2(p)$. This is eflected in Fig. 9 in the fact that the maximal-ratio urve is strictly above the others. The reason for this an be seen at once in Fig. 14; the region of integration or the maximal-ratio system is smaller than it is for the thers and interior to both of the others. Hence, no natter what fading distribution is involved, the joint ensity function will still be non-negative and, therefore, s integral over the maximal-ratio region of Fig. 14, e., $G_2(p)$, will still be smaller than for the others. Thus, he maximal-ratio curve of Fig. 9 would be above the thers for any fading distribution.

Of course, this result could also be seen from the fact hat the maximal-ratio system yields an output power atio that is indeed maximal. But there is no similar act to use as a guide in comparing the other two, for vhich we must rely on Fig. 14. It can be seen there hat the areas of the selection and equal-gain regions re identical and that neither region includes the other. This would lead one to suspect that the relative perormance of selection diversity and equal-gain diversity depends on the form of the fading distribution. In order to discuss this, consider the nature of the possible departures from the Rayleigh distribution.

For purposes here, two cases may be distinguished: fading distributions more disperse (broader or more smeared-out) than the Rayleigh distribution, which are associated with frequent or persistent deep fades, and distributions less disperse (narrower or shallower) than the Rayleigh distribution, which are associated with shallow fading. These cases are illustrated in Fig. 15, together with the Rayleigh distribution. Curve (b), one of a family of distributions given by Rice, illustrates the less disperse or shallow fading often encountered at frequencies below UHF.[21] Curve (c) illustrates the more disperse case sometimes found in short-range UHF circuits and in high- and medium-frequency systems.

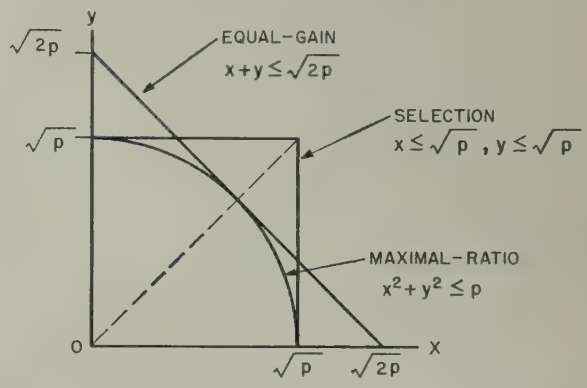

Fig. 14—Regions of integration for three types of dual diversity systems, after Altman and Sichak [8].

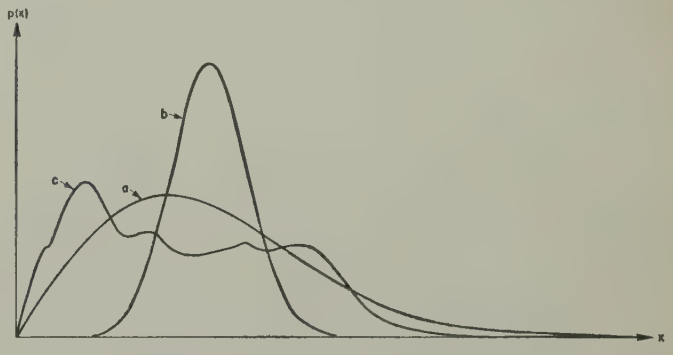

Fig. 15—Representative fading distributions. (a) Rayleigh density function. (b) Representative Rice distribution. (c) Typical distribution of the unpleasant sort often observed at frequencies below UHF.

Returning now to Fig. 14, it is not difficult to see that independent shallow fading will tend to improve the performance of an equal-gain system. This is because the height of the joint density function will be small in the region near the origin common to both the equal-gain and selection regions, and the bulk of the density function will be "pushed out" along the diagonal where

[21] R. W. E. McNicol, "The fading of radio waves of medium and high frequencies," *Proc. IEE*, vol. 96, pp. 517–524; October, 1949.

it will contribute more to the integral over the selection region than to the integral over the equal-gain region. Thus, an equal-gain combiner will continue to outperform selection diversity in the presence of shallow fading; indeed, its performance will more nearly approximate a maximal-ratio system. This can also be seen directly by considering the basic operation of a two-channel equal-gain system, and visualizing the case where the two signals are approximately constant.

However, this is not true for the more disperse distributions. Consider first the case where the individual amplitude ratios x and y are rectangularly distributed,[22] say on $0 \leq x \leq A$ and $0 \leq y \leq A$, with a joint density function $p(x, y) = 1/A^2$ on the square $x \leq A$, $y \leq A$. It is then easy to see that for values of p for which both the equal-gain and selection regions fit inside this square (*i.e.*, for $\sqrt{2p} < A$, or $p < A^2/2$), their distribution functions are identical. That is, with respect to the smaller values of p, the equal-gain and selection systems yield identical performance. Next, suppose the independent amplitude ratios are exponentially distributed, say e^{-x} and e^{-y}, so that their joint density function is $e^{-(x+y)}$. Noting that the contours of constant height of this density function are the lines $x+y=$constant, parallel to the boundary of the equal-gain region, it is easy to see that the integral of this density function over the equal-gain region is strictly larger than it is over the selection region. This can also be verified by direct computation, as the relevant distribution functions are easily evaluated. Hence, for exponential amplitude fading, the local reliability gain of dual equal-gain diversity is, for any percentage, strictly less than it is for dual selection diversity.

It is thus seen that the relative performance of selection diversity and equal-gain diversity depends to some extent on the fading distribution involved. Consequently, the application of equal-gain diversity should be viewed with a modicum of caution in cases where very disperse fading distributions might be encountered. However, the exponential distribution used above is probably extreme in this respect,[22] and even for this case, the equal-gain system is not significantly poorer than selection diversity. For high reliability percentages, the local reliability gain of the dual maximal-ratio system over either the selection system or the equal-gain system is exactly (approximately) $10 \log_{10} (4/\pi) = 1.05$ db for rectangular (exponential) fading.

It was noted above that the maximal-ratio data of Fig. 8 were independent of the fading distribution. However, the mean power ratios of equal-gain systems do depend on the distribution, but only to the extent of the parameter $r^2 = (\bar{x})^2/\overline{x^2}$ of (44). For the rectangular and exponential distributions considered above, $r^2 = \frac{3}{4}$ and $r^2 = \frac{1}{2}$, respectively, indicating that the average local power ratio of an equal-gain system is not substantially degraded by even very disperse fading distributions. Unfortunately, no such simple and clear dependence of the selection diversity mean values on the form of the distribution exists. The result $\bar{p} = \sum_{k=1}^{N} (1/k)$ of (18) is intimately wrapped up with the Rayleigh distribution, not merely the first two moments. But it is certainly clear that moderate changes in the form of the fading distribution could not lead to substantial changes in the selection diversity values of Fig. 8.

VIII. Relative Effects of Correlated Fading

Two smoothly varying random variables such as the x_j cannot, in general, be strictly independent. Of course, they may fail to be even approximately independent. It is therefore of interest to estimate the effect of dependent fading.

It is convenient to estimate this in terms of a parameter called the correlation coefficient. For two random variables x and y with positive variances[2] σ_x^2 and σ_y^2, this is defined by

$$\rho_{xy} = \frac{\langle (x - \bar{x})(y - \bar{y}) \rangle}{\sigma_x \sigma_y}, \tag{45}$$

which reduces readily to

$$\rho_{xy} = \frac{\overline{xy} - \bar{x}\bar{y}}{\sigma_x \sigma_y}. \tag{46}$$

If x and y are independent, then $\overline{xy} = \bar{x}\bar{y}$.[2] Hence, if x and y are independent, then $\rho_{xy} = 0$. It is known[23] that $-1 \leq \rho_{xy} \leq 1$, and $\rho_{xy} = \pm 1$ if and only if $y = \pm ax + b$ $(a > 0)$. x and y are said to be correlated if $\rho \neq 0$, uncorrelated if $\rho = 0$, and partially correlated if $0 < |\rho| < 1$.

The problem of correlated fading in selection diversity systems has been studied by Staras [7] and others [3], [11], [13]. (See Appendix V for certain questions related to this subject.) Packard [14] and Bolgiano, *et al.*,[8] have studied this problem for two-channel maximal-ratio systems. Quite recently, Pierce[24] and Stein[25] independently studied correlated fading in N-channel maximal-ratio systems, and their results will be published in the near future. Some of Staras' results will simply be reproduced here in Fig. 16, in a form suitable for direct comparison with Fig. 9. The curve $\rho = 1$ is the Rayleigh fading curve of Fig. 9, while $\rho = 0$ denotes the dual selection diversity curve of that figure. It can be seen that approximately half of the uncorrelated local reliability gain is realized even for $\rho = 0.8$, and that the effect is negligible for $0 < \rho < 0.3$.

To consider the relative effect of correlated fading on

[22] So far as conventional applications are concerned. It should be noted that it is not extreme, or even sufficient, for postdetection distributions in FM systems, or special applications, such as that of Price and Green, *op. cit.*

[23] Cramér, *op. cit.*, p. 265, or other standard sources. It is also known that the vanishing of ρ_{xy} does not necessarily imply that x and y are independent.

[24] J. N. Pierce, Air Force Cambridge Res. Center, Bedford, Mass., private communication.

[25] S. Stein, Hycon Eastern, Inc., Cambridge, Mass., private communication.

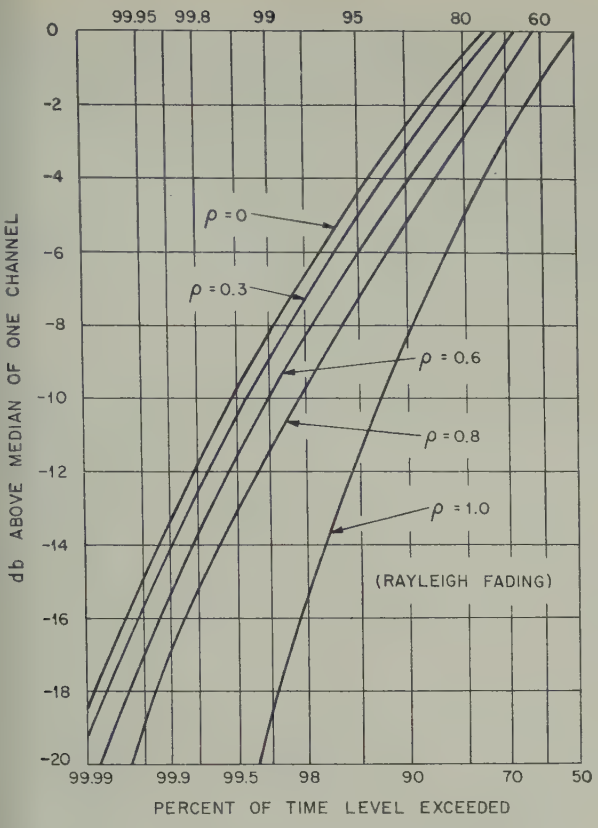

Fig. 16—Dual selection diversity distributions, Rayleigh fading, for various degrees of correlation.

ıe other systems, refer once again to Fig. 14. Now, in rms of the joint density function, there are two major fects of correlation: first, the mass of the density ınction tends to concentrate around the diagonal line $=x$; second, the mass tends to be pulled back nearer ıe origin. The first effect is simply an expression of the ct that as the correlation increases, the probability ıat y can differ appreciably from x necessarily de-eases. (Variables with the same distribution are being ınsidered here.) The second fact can be inferred from ıe behavior of Fig. 16. Given these facts, it is not diffi-ılt to see from Fig. 14 that appreciable correlation will, anything, tend to improve the performance of equal-ıin diversity, relative to selection diversity. (Of course, l three systems degrade in an absolute sense with in-reasing correlation.) Indeed, as ρ approaches 1, when ıe density function approaches zero except on the line $=x$, it is clear that the equal-gain system approaches ıe maximal-ratio system in performance. This can also e seen by considering the basic operation of the two ystems. From these considerations, it is not difficult to sualize the way in which the maximal-ratio and equal-ıin curves of Fig. 9 follow the selection diversity curves Fig. 16. At $\rho=1$, the dual maximal-ratio and equal-ıin curves coincide and are uniformly 3 db above the lection curve for $\rho=1$.

With respect to the average values of Fig. 8, the aximal-ratio data are unaltered by correlated fading. The equal-gain values actually increase toward the maximal-ratio values with increasing correlation. This can be seen either from physical considerations, or by noting that the terms $\bar{x}_i\bar{x}_j$ of (42) are replaced by $\overline{x_ix_j}$; for $\rho>0$, $\overline{x_ix_j}>\bar{x}_i\bar{x}_j$, and in fact $\overline{x_ix_j}$ approaches 1 as ρ_{ij} approaches 1. In contrast, the selection diversity values of Fig. 8 approach zero as the ρ_{ij} approach 1, as is easily seen.

In space-diversity communication systems, an antenna separation of 30 to 50 wavelengths is typically required to obtain correlation coefficients consistently less than 0.3. However, 10 to 15 wavelengths will often yield coefficients less than 0.6. Van Wambeck and Ross[26] measured the performance of certain HF selection diversity systems directly, without measuring correlation coefficients, and apparently found that even shorter spacings led to useful results. More recently, Grisdale, *et al.*,[5] have obtained numerous data bearing on this question in the 6- to 18-mc region.

IX. Variable Local Noise Powers

Many of the data above were obtained on the assumption $\overline{n_j^2}=$constant. This will not be usually strictly true and in many cases will not even be approximately true. If the noises are principally due to interference from remote sources, the $\sqrt{\langle n_j^2\rangle}$ themselves may well follow the Rayleigh distribution, a case that has recently been studied by Bond and Meyer [12] for dual selection diversity. Related material has also been given by Clarke and Cohn.[27] If the n_j are principally due to receiver front end noise, then the $\overline{n_j^2}$ may be approximately constant; the actual amount of fluctuation to be expected is a function of the noise bandwidth and the duration T of the local averages. This fluctuation has been studied by Rice,[28] whose results are quite useful in determining a suitable value of T.

In terms of the analysis above, the principal effect of variable $\overline{n_j^2}$ is to modify the distribution of the $p_j=x_j^2/\overline{n_j^2}$ with results as discussed in Section VII above. (The distribution of the p_j becomes more disperse as the noise power fluctuations increase.) It is not difficult to obtain quantitative estimates of the degradation in particular cases. It should be pointed out that extreme fluctuations in noise power can lead to very poor performance of an equal-gain system, which has no provision for cutting off a very noisy channel, in contrast to the maximal-ratio and selection systems.

[26] S. H. Van Wambeck and A. H. Ross, "Performance of diversity receiving systems," Proc. IRE, vol. 39, pp. 256–264; March, 1951.
[27] K. K. Clark and J. Cohn, "Carrier-to-noise statistics for various carrier and interference characteristics," Proc. IRE, vol. 46, pp. 889–895; May, 1958.
[28] S. O. Rice, "Filtered thermal noise—fluctuation of energy as a function of interval length." *J. Acoust. Soc. Amer.*, vol. 14, pp. 216–227; April, 1943. For additional results, see also, "Mathematical analysis of random noise," *Bell Sys. Tech. J.*, vol. 24, pp. 46–156; January, 1945. (Section 3.9, p. 87 ff.) These results have recently been extended by D. Slepian, "Fluctuations of random noise power," *Bell Sys. Tech. J.*, vol. 37, pp. 163–184; January, 1958.

X. Failure of the Noises to Be Locally Incoherent

The failure of assumption (C) would have no effect on selection diversity systems, for which the assumption $\overline{n_i n_j}=0$ if $i\neq j$ has no relevance whatever. However, this assumption is of vital importance for the maximal-ratio and equal-gain systems, as will be seen.

There are essentially two ways in which $\overline{n_i n_j}$ may fail to be identically zero, the first of which is simply due to the fact that the average $\overline{n_i n_j}$ is over a short interval of duration T and the local average $\overline{n_i n_j}$ will fluctuate about zero if the noises are basically unrelated. The amount of fluctuation will decrease as T is increased and will be small if the lowest frequency of the noise is large in comparison to $1/T$. In this case, the $\overline{n_i n_j}$ terms will be negative as often as positive and will simply contribute a small perturbation to the output noise power $\overline{n^2}$ of a maximal-ratio or equal-gain system. This case is not troublesome.

The troublesome case arises when the noises have a definite positive correlation, as can happen, for example, in a postdetection combiner when the noises stem largely from sources of external interference. To consider this, let $\overline{n_j^2}=1$ and $\overline{n_j}=0$; then $\rho_{ij}=\overline{n_i n_j}$ is the correlation of n_i and n_j. (Note that the local correlation over intervals of length T, in contrast to the correlation over length T_1 of the x_j discussed in Section VIII above, is considered here.) Let $\rho_{ij}=\rho$ if $i\neq j$. Then the output local noise power of an equal-gain system becomes

$$\begin{aligned}\overline{n^2} &= \left\langle \left[\sum_{j=1}^{N} n_j \right]^2 \right\rangle \\ &= \sum_{j=1}^{N} \overline{n_j^2} + \sum_{i\neq j} \overline{n_i n_j} \\ &= N[1+(N-1)\rho], \end{aligned} \tag{47}$$

instead of $\overline{n^2}=N$. Hence, the local noise power is increased by the factor $[1+(N-1)\rho]$, which is to say the output power ratio $\bar{p}$ of (42) is decreased by this factor, which may not be trivial. To see how untrivial it can be, consider $\bar{p}$ for an equal-gain system. Eqs. (45) and (46) become

$$\begin{aligned}\bar{p} &= \frac{\sum \overline{x_j^2} + \sum_{i\neq j} \overline{x_i x_j}}{N[1+(N-1)\rho]} \\ &= \frac{N+N(N-1)r^2}{N[1+(N-1)\rho]} \\ &= \frac{1+(N-1)r^2}{1+(N-1)\rho}, \end{aligned} \tag{48}$$

which reduces to (46) when $\rho=0$. Hence , if $\rho>r^2$—a situation by no means impossible—it would follow that $\bar{p}(1)>\bar{p}(2)$; *i.e.*, the average local power ratio of a two-channel equal-gain system would be less than for a single channel, and the performance gets worse as the number of channels is increased. It is probably gratuitous to point out explicitly that, in such a case, it would be much better to use a selection diversity system, for which (18) would still hold. Similar considerations show that the average local noise power of a maximal-ratio system—by which is meant one for which the coefficients are given by (14), though this is no longer "maximal"—is increased by the factor $[1+(N-1)\rho r^2]$.

It follows that the use of maximal-ratio or equal-gain diversity in circumstances where the noise voltages may be highly correlated is hazardous.

XI. Predetection vs Postdetection Combining

In systems where the power ratio at the output of the detector is essentially the same as at the input, there is no fundamental change required in the conclusions developed above. Of course, there are always practical differences between predetection and postdetection combining; *e.g.*, a predetection maximal-ratio or equal-gain combiner will require the addition of phase-control circuitry in order to satisfy the local-coherence assumption (B). On the other hand, predetection selection diversity will sometimes produce smaller switching transients than postdetection selection. Once phase control is established, it is easier to satisfy the conditions (B) and (C) required for maximal-ratio and equal-gain combiners in the case of a predetection system.

However, substantial changes are required in the case of FM systems with a large deviation ratio, or in other bandwidth-exchange systems with a pronounced threshold effect. In such systems, an SNR at the detector input that is more than a few db above threshold yields a large output ratio, while an input ratio that is more than a few db below threshold yields a very small output ratio. That is, the output ratio changes from "completely useful" to "completely useless" with a few db change of input ratio. This fact has important consequences.

To begin with, a Rayleigh distribution of input signal strength for an FM system will emphatically not lead to a Rayleigh distribution of the postdetection amplitude ratio. Hence, the distribution-sensitive results of Figs. 8–13 and Tables I and II are not realistic for postdetection combining in FM systems. Furthermore, equal-gain combiners are not even suitable for postdetection combining in conventional FM systems; this may be regarded as a consequence of the fact that the detection gain of such systems is not constant. An alternative point of view would be that the distribution of the amplitude ratios at the input of the combiner would be such as to eliminate the equal-gain combiner from consideration; cf. (36), and note the unfortunate effect if any one of the $\overline{n_j^2}$ becomes large.

Of course, a maximal-ratio system can be used for postdetection combining in an FM system. The requirement $a_j=x_j/\overline{n_j^2}$ for the coefficients insures that any channel with large $\overline{n_j^2}$ contributes very little to the output. However, a maximal-ratio system will not yield much improvement over selection diversity in such circumstances. It will eliminate switching transients, but

otherwise will not usually make a significant difference in the operation of the system. This can be seen on the basis of various qualitative considerations. When dealing with postdetection combination in sharp-threshold FM systems, at least for $N \leq 8$, it would probably be best to use only the selection diversity values of Table II, whether selection or maximal-ratio diversity is actually used. In any event, the actual local reliability gains of such maximal-ratio systems—which could be computed from specific detector characteristics, such as those given by Middleton[29] or obtained by measurement—would certainly be less than the maximal-ratio values in Table II. A specific distribution computed on the basis of a highly simplified detector characteristic has been given. [16]

If the local reliability gain is defined in terms of the transmitter power required to maintain the input level of the detector above a certain value for more than a specified percentage of time, then the selection diversity values of Table II are applicable whether the selection is predetection or postdetection. It is clear that the operation is identical in either case. Furthermore, the maximal-ratio and equal-gain data of Table II are completely applicable to predetection combining, as is easily seen. Accordingly, the full advantages of maximal-ratio and equal-gain combiners can be realized in FM systems when and only when they are employed before detection. Taking the selection values of Table II as being the gains obtained by a postdetection maximal-ratio combiner, the differences between the maximal-ratio and selection values of Table II then illustrate the added advantage of predetection maximal-ratio or equal-gain combining. This may be regarded as due to an effective lowering of the detector threshold resulting from these techniques.

An additional advantage of predetection combining in FM systems is that FM multipath distortion can be reduced by this method. It has been shown by Adams and Mindes [16], both theoretically and experimentally, that a predetection equal-gain combiner yields substantially less multipath distortion than is obtained with a postdetection maximal-ratio combiner, when both are operated under the same circumstances.

Instrumentation for postdetection maximal-ratio combining has been discussed by Kahn [6] and by Morrow, *et al.*,[11] for what amount to AM systems, and by Mack[30] for FM systems. An ingenious predetection maximal-ratio combiner has been devised by Granlund.[31] A particularly elegant predetection equal-gain combiner has been developed by the Federal Telecommunication Laboratories (now the ITT Laboratories), indicated in Fig. 17. This combiner, called simply a phase combiner in FTL literature, is the same one used in the experiments reported by Adams and Mindes [16]. The phase control and adder circuits require only two semiconductor diodes and 16 passive linear elements. Phase control is established via a phase discriminator, the output of which is applied as a bias voltage to one of the local oscillators. This corrects the phase of the local oscillator via Miller-effect changes in the oscillator tube capacity.

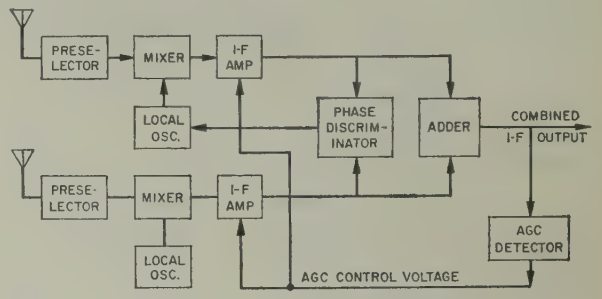

Fig. 17—FTL predetection equal-gain combiner. This can be used with any type of modulation.

The problem of adequate phase control for predetection maximal-ratio or equal-gain combining leads naturally to the next topic, namely

XII. Failure of the Local-Coherence Condition (B)

It is obviously of interest to estimate the possible degradation in performance of maximal-ratio and equal-gain combiners when the local-coherence condition (**B**) is not satisfied. The following treatment is due to Stein.[32]

Recall that (**B**) was the assumption $s_j(t) = x_j m(t)$ where x_j was the slowly varying local rms value of s_j. If the s_j are not all in phase, we must write $s_j(t) = x_j m_j(t)$, where the m_j have different phases. Consider the case $m_j(t) = \sqrt{2} \cos(\omega t - \phi_j)$ where the ϕ_j are locally constant in the sense that the x_j are. Then $\langle m_j^2 \rangle = 1$ and $\langle s_j^2 \rangle = x_j^2$, as before, averaging over a few cycles (or more) of ωt. Then, for any locally linear combiner of the type (6),

$$\overline{s^2} = \left\langle \left[\sum_{j=1}^{N} a_j s_j \right]^2 \right\rangle$$

$$= \left\langle \sum a_j^2 x_j^2 2 \cos^2(\omega t - \phi_j) + \sum_{i \neq j} a_i a_j x_i x_j \cdot 2 \cos(\omega t - \phi_i) \cos(\omega t - \phi_j) \right\rangle$$

$$= \sum a_j^2 x_j^2 + \sum_{i \neq j} a_i a_j x_i x_j \langle 2 \cos(\omega t - \phi_i) \cos(\omega t - \phi_j) \rangle$$

$$= \sum a_j^2 x_j^2 + \sum_{i \neq j} a_i a_j x_i x_j \cos(\phi_i - \phi_j), \tag{49}$$

where the last step used $2 \cos A \cos B = \cos(A+B)$

[29] D. Middleton, "On theoretical signal-to-noise ratios in FM receivers: a comparison with amplitude modulation," *J. Appl. Phys.*, vol. 20, pp. 334–351; April, 1949.

[30] C. L. Mack, "Diversity reception in UHF long-range communications," Proc. IRE, vol. 43, pp. 1281–1289; October, 1955.

[31] J. Granlund, "Topics in the Design of Antennas for Scatter," Lincoln Lab., M.I.T., Lexington, Mass., Tech. Rep. No. 135, pp. 105–113; November, 1956. See also recent Quarterly Progress Reports of the M.I.T. Res. Lab. of Electronics.

[32] S. Stein, private communication; August, 1957.

$+\cos(A-B)$ and the fact that $\langle \cos(2\omega t-\phi_i-\phi_j)\rangle = 0$. Eq. (49) may also be written

$$\overline{s^2} = \sum_{i,j} a_i a_j x_i x_j \cos(\phi_i - \phi_j) \tag{50}$$

since $\cos(\phi_j-\phi_j)=1$, and this reduces to

$$\overline{s^2} = [\sum a_j x_j]^2 = \sum_{i,j} a_i a_j x_i x_j \tag{23'}$$

when $(\phi_i-\phi_j)=0$. Let p denote the output power ratio of the general combiner (6) when (23') holds, and p' denotes the same for the phase-degraded case (50). Then (assuming (**C**) still holds, so that $\overline{n^2}=\sum a_j^2\overline{n_j^2}$)

$$\begin{aligned} p' &= \frac{\sum_{i,j} a_i a_j x_i x_j \cos(\phi_i - \phi_j)}{\sum a_j^2 \overline{n_j^2}} \\ &= \frac{\sum_{i,j} a_i a_j x_i x_j \cos(\phi_i - \phi_j)}{[\sum a_j x_j]^2} \cdot \frac{[\sum a_j x_j]^2}{\sum a_j^2 \overline{n_j^2}} \\ &= kp, \end{aligned} \tag{51}$$

where

$$k = \frac{\sum_{i,j} a_i a_j x_i x_j \cos(\phi_i - \phi_j)}{[\sum a_j x_j]^2} \tag{52}$$

is the "phase degradation ratio" p'/p.

Apart from the fact that $0 \le k \le 1$, not much can be said about k in the general case (52) in the absence of additional information about the ϕ_j. It is easy to see that k may actually vanish; *e.g.*, $N=2$, $a_1=a_2=x_1=x_2=1$, $\phi_1-\phi_2=180°$. Then $p'=k=0$, which is entirely to be expected when adding two signals of equal magnitudes and opposite phases. This illustrates the fact that the condition (**B**) cannot be ignored. On the other hand, it is not necessary that it should be satisfied with great precision. Suppose that the magnitudes of the phase differences, $|\phi_i-\phi_j|$, do not exceed 90°, and let Δ = maximum of $|\phi_i-\phi_j|$, $i, j = 1, 2, \cdots, N$; $0 \le \Delta \le 90°$. Then $0 \le \cos\Delta \le \cos(\phi_i-\phi_j)$, so

$$k \ge \frac{\sum_{i,j} a_i a_j x_i x_j \cos\Delta}{[\sum a_j x_j]^2} = \cos\Delta, \tag{53}$$

or

$$p' \ge p \cos\Delta. \tag{54}$$

That is, the local power ratio is not reduced by more than $\cos\Delta$, or $-10 \log_{10}\cos\Delta$ db, in any combiner whatever of the general type (6), provided $\Delta \le 90°$. In particular, this conclusion holds for equal-gain and maximal-ratio combiners. Thus, to restrict the reduction in p due to imperfect phase control to 1 db or less, it is only necessary to maintain the phases within 37.5° of each other, while 51° is sufficient to guarantee a maximum loss of 2 db. Furthermore, it is clear that the estimate $p\cos\Delta$ is actually conservative.

XIII. Long-Term Variability

Recall that the distributions of the x_j and p, and mean values of these quantities, were to be determined in intervals of length T_1, relative to which the x_j were assumed to be approximately Rayleigh-distributed and approximately independent. It is important to understand the nature of this situation.

It is an experimental fact that, for a suitable choice of T_1, both of these assumptions are often satisfied. It is also an experimental fact that if T_1 is made too long or too short, neither assumption is satisfied. Hence, the approach used above and all of the results developed above depend entirely on the use of finite intervals of observation that are neither too long nor too short.

Specific suitable values of T_1 depend on the circumstances, primarily the carrier frequency and transmission distance. Of course, it is necessary to understand that the results of Figs. 8–13, etc., refer only to intervals of length T_1, whatever this may be. Specific values are roughly as follows for long-range transmission. At frequencies below VHF, intervals of 30 minutes to an hour are usually suitable. In VHF ionospheric scatter systems, values of one or two minutes usually seem to be appropriate; in UHF and SHF tropospheric systems, intervals of five to 30 minutes are often used.

It is manifestly necessary to consider the behavior of diversity systems over longer intervals than those of length T_1. This may be done as follows. The previous results were obtained using a Rayleigh distribution (9) of unit mean square, with a definite median value $M_0 = \sqrt{\log_e 2}$. Now, the experimental fact is that the fading distributions observed over different intervals of length T_1 will not usually have the same median values. However, the medians obtained in two adjacent or overlapping intervals of length T_1 will not usually differ by very much. One way to represent this fact is to let $M = M(t)$ denote the median of the distribution obtained in the interval from $t-T_1$ to the present time t. Then this median function is a continuous function of time and the experimental fact is that $M(t)$ is usually approximately constant over intervals of length T_1. It should be clear that this does not depend on having the distributions, for which the values of $M(t)$ are the medians, all be of the same form, Rayleigh or other.

This may be used as follows. If x is any random variable with a nonzero median M_0 and M is any nonzero constant, then it is easy to see that $y=(M/M_0)x$ has a distribution of the same form as that of x, differing only in the scale factor M/M_0, and that the median value of y is M. (The only reason for writing this scale factor in terms of the medians is that these are easily determined experimental quantities.) Then, instead of taking the local rms signals to be the x_j with a fixed median M_0, the actual local rms signals may be written as $y_j=(M_j/M_0)x_j$, with median values M_j, relative to a period of length T_1. Here, however, another experimental fact enters. The medians M_j are usually approximately the same for different channels, and we

may write $M_j = M$, $j = 1, 2, \cdots, N$. If the median function $M(t)$, above, is approximately constant over intervals of length T_1, we may take $M = M(t)$.

To apply this to our previous results, note that the local linearity of (6) implies that any common scale factor multiplying the signal components s_j may be taken outside the sum $s = \sum s_j$. Hence, the combined output signal $s(t)$ is simply multiplied by M/M_0 and the local power ratio becomes $(M/M_0)^2 p$ wherever p was before. This becomes even simpler when expressed in decibels. Let

$$\begin{aligned} w &= 10 \log_{10} [(M/M_0)^2 p] \\ &= 20 \log_{10} M + 10 \log_{10} (p/M_0^2) \\ &= u + v \end{aligned} \tag{55}$$

be the local power ratio in db, where $u = 20 \log_{10} M$ and $v = 10 \log_{10} (p/M_0^2)$. Then this expresses the actual local power ratio delivered by any combiner of the type (6) as the sum of a variable v whose T_1 median does not depend on time and a variable u that is approximately constant over every interval of length T_1. Now, the distributions plotted in Figs. 9–13 are precisely the distributions of the variable v for the conditions of Fig. 8, for different combiners and orders of diversity. Hence, to apply the results of Figs. 9–13 to any particular interval of length T_1, it is only necessary to translate their ordinate scales by $u = 20 \log_{10} M$ where M is the median of the single-channel fading distribution for the interval concerned.

In order to describe the long-term variability of the actual local power ratio w, it is necessary to have information about the long-term variability of the (T_1-) median u. Distributions of u are usually studied in intervals of length T_2 = one month to one year; such distributions are often called distributions of hourly medians, though they should properly be distributions of T_1-medians. Several such distributions for frequencies at VHF and above have been given.[33] Unfortunately, no comparable single source of information for MF and HF systems presently exists; the relevant data are largely scattered in (generally unobtainable) Signal Corps reports, FCC hearing transcripts, and URSI and CCIR documents, though a few such data have been published. Observed distributions of u are sometimes approximately Gaussian (normal) in form, especially at the higher frequencies, which is why the distributions of M are often said to be log-normal.

Once a distribution of u pertinent to the proposed circuit is available, there are two ways it may be used. The first method, which is applicable to high-reliability systems at VHF and above, is to estimate the lowest T_1-median likely to be encountered on the circuit. (The great virtue of these systems is that this minimum value of u is not $-\infty$.) The ordinate scales of Figs. 9–13 are then translated to this value, after which a rational choice among the various possibilities of transmitter power, order and type of diversity system, etc., may be made on the basis of economic and other factors, and on the basis of the local reliability percentage it is desired to maintain during such worst hours. Of course, the data of Figs. 9–13 must be modified in accordance with the discussion of Sections VII to XII if the circumstances so dictate.

The second method is applicable in circumstances where all distributions of v in all intervals of length T_1 are approximately the same.[34] It is then easy to see that the distribution of v in an interval of length T_2 = one year would also be the same; furthermore, the variables u and v of (55) would then be independent, relative to T_2, to a very high degree of accuracy. Then the T_2-distribution of the local power ratio w would be the distribution of the sum of two independent variables with known distributions, and could be computed. It would usually be found that the "exact" determination of the T_2-distribution of w would require numerical methods of integration in (67). Such distributions have been computed by Shimony[35] and Sichak[36] among others. However, Staras [9] has observed that, for the larger values of N, the relevant distributions of v are approximately normal (cf. the $N = 6$ and $N = 8$ curves of Figs. 12 and 13, on which figures a normal distribution would be a straight line) and since the distribution of u is approximately normal, the T_2-distribution of w would therefore[2] approximate a normal distribution with a median and variance respectively equal to the sums of the medians and variances of the u and v distributions. But this approximation is not very accurate for $N \leq 4$.

It should be added, however, that this second method has not been universally accepted by designers of high-reliability systems, for the following reasons. Computing the long-term distribution of w serves to obscure the question of whether the periods of very low signal are a few long periods or many short ones. This question can be important; *e.g.*, there are systems in operation in which the loss of two hours in a year would not be troublesome if split into a number of separated intervals of a minute or two each, but which could be disastrous if concentrated in a single interval of two hours. Since two hours in a year corresponds to the 99.98 per cent exceeded level, it would be necessary to compute the T_2-distribution of w down to something like the 99.999 per cent exceeded level in order to insure approximately the reliability obtained by the first method. However, the empirical distributions on which this computation must ultimately rest are not known to anything approaching this degree of accuracy, and the validity of such a computation would seem to be open to question. In addition, the problem mentioned in footnote 34

[33] Scatter Propagation Issue, Proc. IRE, vol. 43; October, 1955.

[34] It should be noted that such circumstances, however, are not too common in practice.

[35] A. Shimony, Final Rep. MU-156, Evans Signal Lab., Fort Monmouth, N. J., (cited in footnote 36).

[36] W. Sichak, Fed. Telecommun. Labs., Nutley, N. J., Tech. Memo. 619; December, 1956. See Appendix D, "Diversity Theory."

would often infect such a computation.

Two additional points should also be noted in connection with long-term distributions of w. The first is that the variability or dispersion of w will increase as the dispersion of the T_1-median u increases. In other words, the variability of v will tend to be obscured by that of u. However, it is precisely the variability of v that can be reduced by diversity techniques, while that of u cannot. It has been noted[36] that w distributions for different orders of diversity show less difference than would be indicated by Table II, but this is simply a reflection of the dispersion contribution by u. Thus, computing long-term distributions of w tends to obscure the gains (Table II) that actually *are* realized by diversity techniques.

The second point to be noted is that any long-term distribution of w is highly specific to the circuit for which it was computed, because u distributions are highly specific. This is indicated in Fig. 18,[37] which shows percentage points of u distributions as a function of distance at 400 mc. (Note that Fig. 18 gives only the distributions of the T_1 median "scatter" loss; the free-space loss has been subtracted out.) It can be seen that the dispersion of u decreases with distance; *e.g.*, the interdecile range is about 12.5 db at 200 miles, but only 5 db at 600 miles. This indicates that a long-term distribution of w would only be valid for the distance on which the distribution of u was based.

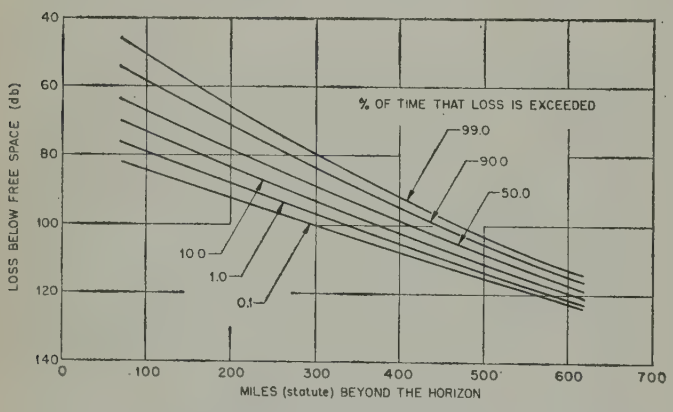

Fig. 18—Distributions of hourly medians as a function of distance, wintertime propagation at 400 mc, experimental data from several Lincoln Laboratory circuits. (After Morrow[37].)

XIV. Case of Unequal Median Signals

Most of the material above presupposed that the T_1-medians for the several channels were all the same. Experimentally, this is found to be a reasonable approximation in most cases, provided that the interval length T_1 is not made too short. However, there are cases, most especially angle diversity,[8–10] in which it is not a reasonable approximation. The first treatment of this problem apparently was given in [3]. It is quite simple to plot selection diversity distributions for unequal medians or even for dissimilar distributions; the identical factors $G(p)$ of (16) are simply replaced by the proper distribution functions. Maximal-ratio distributions for unequal-median Rayleigh signals can also be expressed explicitly. Unfortunately, this is not true of complete equal-gain distributions (*cf.* Appendix IV). However, it would be possible to obtain the low-signal ends of such distributions by taking the first few terms of a power series, but a detailed analysis of this problem would appear to be premature at the present time.

XV. Experimental Results

Experimental data relating to diversity systems have been given by several workers, including Glaser and Van Wambeck,[38] Van Wambeck and Ross,[26] Glaser and Faber,[4] and Grisdale, *et al.*[5] It is unfortunate for our present purposes that most of these data relate to selection diversity only; clear-cut and unambiguous experimental data bearing on the comparative performance of the three combining techniques studied above are so rare to be as essentially nonexistent. It is hoped that some comparative experimental results will be available within the next year.

Perhaps the best single datum presently available was obtained in unpublished experiments conducted by the Signal Corps a few years ago. Two high-frequency systems were compared, one of which used dual maximal-ratio diversity and the other used something approximating selection diversity. It appeared that the maximal-ratio system yielded an average power ratio of 1.0 to 1.5 db above the selection system when averaged over periods of about 30 minutes.[39] This compares very favorably with the value 1.25 db entered in the "selection" column of Table I for $N=2$. However, there were many periods during which the performance of the maximal-ratio system was inferior to the other. This could probably be traced to the failure of one or both of the conditions (**B**) and (**C**) during such periods, which would not affect a selection system.

XVI. Conclusions

Perhaps the most important conclusion to be drawn is that, all things considered, no one of the diversity combining techniques studied deserves to be called "the optimum system." All three have their merits and defects, and the one to be used will depend on the circumstances. However, the simplicity and efficacy of the equal-gain system suggest that this may well become the principal standard of the art. In addition to the data set forth above, it should be especially noted that the instrumentation for an equal-gain combiner is completely independent of what one chooses to think of as a SNR. The importance of this fact is considerable.

[37] W. E. Morrow, Jr., "Etude de systemes de radiocommunication troposphérique UHF a longue distance," *Onde Elect.*, vol. 37, pp. 444–449; May, 1957.

[38] J. L. Glaser and S. H. Van Wambeck, "Experimental evaluation of diversity receiving systems," Proc. IRE, vol. 39, pp. 252–255; March, 1951.

[39] F. E. Bond and H. F. Meyer, Signal Corps Eng. Labs., Fort Monmouth, N. J., private communication; June, 1957.

Appendix I

Certain Facts About Probability Theory

It will be recalled[2] that, in general, a distribution function $P(x)$ is the probability that (some random variable) is less than or equal to x. A particularly simple special case of this arises when the random variable in question is some voltage or current waveform given as a function of time, say $f(t)$, and the probability that $f \leq x$ is simply the fraction of some interval $t_1 - T \leq t \leq t_1$ in which $f \leq x$. In this case, $P(x)$ is determined, for any given value of x, simply by adding up the lengths of the t intervals for which $f(t) \leq x$ and dividing their sum by the total duration of the observation, as indicated in Fig. 19. Instruments for measuring $P(x)$ at selected values of x are known as "totalizers" or "level distribution recorders" and exist in various forms. Another method of obtaining the distribution function of some random variable is to sample it at discrete intervals and count the fraction of sampled values that are $\leq x$; however, it is not difficult to see that this will lead to the same $P(x)$ as defined above. The associated density function[2] $p(x) = dP(x)/dx$, so that $p(x)dx = dP(x)$.

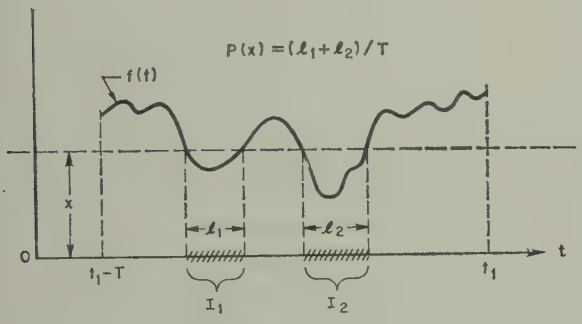

Fig. 19—Definition of $P(x)$ = fraction of the time of observation that $f(t) \leq x$.

The central purpose in using such distribution functions in radio engineering stems from the fact that many different individual waveforms have approximately the same distribution function, or at least have distribution functions that differ in describable ways, as in Section XIII. This is an experimental fact, no more, but, what is important, no less. Thus, in circumstances where the distribution function of some waveform can be approximately predicted from either theoretical or empirical grounds, one has available a method of predicting many important facts about the situation.

One such fact, of the first importance, is that all time averages of f in the interval $t_1 - T \leq t \leq t_1$ are given by the moments[2] of the distribution function $P(x)$. For example, suppose one is interested in the average value of $f(t)$. Then

$$\frac{1}{T}\int_{t_1-T}^{t_1} f(t)dt = \int_{-\infty}^{\infty} xp(x)dx = \int_{-\infty}^{\infty} xdP(x); \qquad (56)$$

i.e., $\bar{f}$ is the first moment of the distribution. More generally, for any value of n, the time average of $[f(t)]^n$ is given by the nth moment of the distribution:

$$\frac{1}{T}\int_{t_1-T}^{t_1} [f(t)]^n dt = \int_{-\infty}^{\infty} x^n dP(x), \qquad (57)$$

a result that is especially useful in computing the average power when f is a voltage or current and $n=2$. In the light of (57), $\overline{f^n}$ or $\langle f^n \rangle$ or $\overline{x^n}$ or $\langle x^n \rangle$ can be and is written interchangeably for such averages, using whichever notation seems most convenient for the expression involved.

It is important to understand the sense in which (57) is applicable. No theory or representation or mathematical model whatever can predict the particular distribution function of a particular waveform in a particular interval exactly, but to the extent it can be predicted by whatever means, (57) is applicable. In many applications, one uses a specific mathematical model distribution (*e.g.*, the Rayleigh distribution, much used in the body of this paper) for predicting facts such as averages of the form (57), but with a clear understanding that any realized distribution function can only approximate the Rayleigh distribution, however long or short the interval of observation. But the approximation may be very close. In cases where the nature of the possible departures from the model distribution can be estimated, and there are many such cases, the possible departures in the corresponding time averages can similarly be estimated via (57). [Some statisticians and noise theorists may be bothered by the absence from this discussion of any reference to the classical notions of sample and population. The reason for this is that a parent population in the classical sense does not usually exist in this environment. (See Section XIII.) No fixed distribution can serve as a population distribution for any non-stationary process. In the notation of Section XIII, it would be possible, but not necessarily desirable, to discuss parent populations for T_2-distributions, but certainly not T_1-distributions. One may, however, discuss a "distribution" of distributions, as is done in engineering language in that section. It would be a simple matter to provide a more formal framework for this material by defining suitable classes of functions f; *e.g.*, all those f whose half-hour local distribution functions (in the sense of Fig. 19) were all within a specified distance (in the sense of Lévy's metric) of some Rayleigh distribution function, and whose half-hour medians (*ipso facto* unique) had yearly distribution functions within a specified distance of a fixed log-normal distribution function. This class is non-empty for positive distances, and would suffice for most of the purposes of Sections II through VI. One could similarly replace our heuristic language about approximate constants with a more formal treatment that was liberally seasoned with epsilons and deltas and rigorous inequalities. However, there is probably little to be gained by this formalism in the present context.]

These considerations above extend directly to several random variables given as in Fig. 1 and their corre-

sponding multidimensional distribution functions. Thus, all of the multidimensional probability theory given by Bennett[2] can be directly applied to our present circumstances. Of course, such distributions will generally depend on the present time t_1 and the duration T, but for suitable (not necessarily long) values of the duration T, this dependence may be considered to be negligible for certain engineering purposes.

It is quite well known that averaging is a linear operation; *i.e.*, if x and y are random variables and a and b are constants, then $\langle ax+by\rangle = a\bar{x}+b\bar{y}$. This is clear when considered as time averages and, as an immediate consequence of (56), also holds for the corresponding distribution averages. (Let P_1, P_2, and P_3, denote the distribution functions of f, g, and $f+g$, respectively, and write (56) three times. This does not require independence of f and g.)

Although this fact is well known, such extensive use of it is made in the body of the paper that it is advisable to mention a few consequences here. First, if x_1, x_2, $\cdots$, x_n are random variables, not necessarily independent, and a_1, a_2, $\cdots$, a_n are constants and

$$y = \sum_{k=1}^{n} a_k x_k, \tag{58}$$

then

$$\bar{y} = \sum_{k=1}^{n} a_k \overline{x_k}. \tag{59}$$

In order to consider higher moments than the first, note the simple algebraic fact that $(a_1x_1+a_2x_2)^2 = a_1^2x_1^2 + a_2^2x_2^2 + 2a_1a_2x_1x_2$ can be written $a_1^2x_1^2+a_2^2x_2^2+a_1a_2x_1x_2 + a_2a_1x_2x_1$. More generally, one can write

$$y^2 = \left[\sum_{k=1}^{n} a_k x_k\right]^2 = \sum_{k=1}^{n} a_k^2 x_k^2 + \sum_{i\neq j} a_i a_j x_i x_j. \tag{60}$$

Hence, by (59),

$$\overline{y^2} = \sum_{k=1}^{n} a_k^2 \overline{x_k^2} + \sum_{i\neq j} a_i a_j \langle x_i x_j\rangle \cdot \tag{61}$$

If the x_i are independent, then $\langle x_i x_j\rangle = \bar{x}_i\bar{x}_j$ if $i\neq j$.[40] Then (61) becomes

$$\overline{y^2} = \sum_{k=1}^{n} a_k^2 \overline{x_k^2} + \sum_{i\neq j} a_i a_j \bar{x}_i\bar{x}_j. \tag{62}$$

Hence, if the first two moments $\bar{x}_i$ and $\overline{x_i^2}$ of the x_i are known, the average square of y can be computed without even knowing the distribution of the x_i, much less the explicit distribution of y. It will be seen in several sections of this paper that these simple facts can lead to interesting and important results, some of which are by no means obvious.

Another well-known fact is that a joint density function[2] $p(x, y)$ of two random variables can be integrated over a region in the plane to obtain the probability of the region. Thus, the probability that $x_1<x\leq x_2$, $y_1<y\leq y_2$ is given by

$$\int_{x_1}^{x_2}\int_{y_1}^{y_2} p(x, y)dydx, \tag{63}$$

and the joint distribution function $P(x, y)$ is simply

$$P(x, y) = \int_{-\infty}^{x}\int_{-\infty}^{y} p(s, t)dtds. \tag{64}$$

Notice that both (63) and (64) can be written in the form

$$\int\int_{E} p(x, y)dxdy \tag{65}$$

of an integral of $p(x, y)$ over a certain region E in the x-y plane. In the case of (63), the region is an ordinary rectangle, while in the case of (64), it is a semi-infinite rectangle. The virtue of this geometric approach is that it often enables the expression of an event of practical interest in terms of such a region, not necessarily a "rectangle," after which the probability of the event in question can be computed by integrating the joint density function over the region. Joint density functions of three or more variables can similarly be integrated over regions in space of three or more dimensions. This is used at several places in the body of the paper.

Finally, a few words on computing the distribution functions of sums of independent random variables may be useful. It was pointed out by Bennett[2] that if x and y are independent random variables with density functions p_1 and p_2, respectively, the density function p_3 of the sum $z=x+y$ is given by

$$p_3(z) = \int_{-\infty}^{\infty} p_1(z-y)p_2(y)dy, \tag{66}$$

which is called the "convolution" or "composition" of the density functions p_1 and p_2. (This has sometimes been referred to as "combining" the x and y distributions.) However, in many—possibly most—practical applications, the distribution function of z, *i.e.*, the probability that $z\leq u$, is of more interest than the density function. This can be expressed in terms of the component distribution functions as

$$P_3(u) = \int_{-\infty}^{\infty} P_1(u-y)dP_2(y), \tag{67}$$

which can be seen from (66) by writing $p_2(y)dy = dP_2(y)$ and integrating (66) on z from $-\infty$ to u. The integral (67), which is well known among mathematicians,[41] may be defined as the limit of approximating sums of the form

$$\sum_{k} P_1(u-y_k)[P_2(y_k) - P_2(y_{k-1})], \tag{68}$$

[40] Bennett, footnote 2, p. 619.

[41] Cramer, *op. cit.*, p. 190, (15.12.2), and other sources.

where the y_k form a suitably fine partition of the range of interest. This and other numerical integration techniques may be used to evaluate (67) numerically, at least as easily as a numerical evaluation of (66). (See Appendix IV.) Hence, if the distribution functions of two variables are given numerically and the distribution function of the sum is required, there is no need to transform the given distribution functions into approximate density functions, evaluate (66) numerically, and then sum the resulting approximate density function, a procedure unnecessarily involved, but fairly commonly used.

Appendix II

The Schwarz Inequality

There are several ways of proving the inequality

$$\left[\sum_{j=1}^{N} u_j v_j\right]^2 \leq \left[\sum_{j=1}^{N} u_j^2\right]\left[\sum_{j=1}^{N} v_j^2\right], \tag{19}$$

of which the simplest is perhaps to notice the algebraic identity

$$\left[\sum_{k=1}^{N} u_k v_k\right]^2 = \left[\sum_{k=1}^{N} u_k^2\right]\left[\sum_{k=1}^{N} v_k^2\right] - \frac{1}{2}\sum_{i,j=1}^{N}(u_i v_j - v_i u_j)^2, \tag{69}$$

which can be verified at once simply by expanding both sides. It is clear that (19) follows immediately from (69), for the term

$$\sum_{i,j=1}^{N}(u_i v_j - v_i u_j)^2$$

is obviously non-negative. However, more precise information can be extracted from this. Evidently there is equality holding in (19) if and only if every term in the double sum on the right in (69) vanishes, *i.e.*, if and only if

$$u_i v_j - v_i u_j = 0,\ i, j = 1, 2, \cdots, N, \tag{70}$$

and it is not difficult to see that this will happen if and only if there are constants a and b, not both zero, such that $au_i = bv_i$, $i = 1, 2, \cdots, N$. That is, equality holds in (19) if and only if the u's and v's are proportional. It is this fact that accounts for the "and only if" assertion following (14); the material of Section IV does not justify this assertion.

Appendix III

The Maximal-Ratio Distribution

The characteristic function[2] of the p_j is

$$\phi(t) = \int_{-\infty}^{\infty} e^{itp_j} g(p_j)\,dp_j = \int_0^{\infty} e^{-p_j + itp_j}\,dp_j = \frac{1}{1 - it}, \tag{71}$$

where $i = \sqrt{-1}$ is not an index. The characteristic function of p is then simply

$$\phi_N(t) = [\phi(t)]^N = \frac{1}{(1 - it)^N}, \tag{72}$$

so that the density function of

$$p = \sum_{j=1}^{N} p_j$$

is

$$g_N(p) = \frac{1}{2\pi}\int_{-\infty}^{\infty} e^{-ipt}\phi_N(t)\,dt = \frac{1}{2\pi}\int_{-\infty}^{\infty} \frac{e^{-ipt}}{(1 - it)^N}\,dt. \tag{73}$$

The integral (73) is easily evaluated by contour integration and the residue theorem. The result is

$$g_N(p) = \frac{1}{(N-1)!}\,p^{N-1}e^{-p} \tag{74}$$

for $p > 0$, while $g_N(p) = 0$ for $p < 0$. This is precisely the result (29).

Appendix IV

Computation of the Equal-Gain Distribution

The function $B_N(u)$ of (41) is given recursively by

$$B_N(u) = \int_0^u B_{N-1}(u - t)\,dB_1(t) = \int_0^u B_{N-1}(u - t)B_1'(t)\,dt, \tag{75}$$

as can be seen from (67), where $B_1'(t) = 2te^{-t^2}$ is the Rayleigh density function. Tables of $B_N(u)$ have been constructed[19] from (75) for $N = 2, 3, \cdots, 8$, using an IBM 704 computer. Tables were constructed for various increments Δ of u, ranging from $\Delta = 0.2$ down to $\Delta = 0.02$, and for the range $0 \leq u \leq 17$. The Rayleigh density and distribution functions were generated in the computation program by rational approximations accurate to six decimals. Each value $B_N(u_k)$, where $u_k = k\Delta$, was then computed from

$$B_N(u_k) = \sum_{l=1}^{k}\int_{(l-1)\Delta}^{l\Delta} B_{N-1}(t)B_1'(u_k - t)\,dt, \tag{76}$$

where each integral over the range of length Δ was computed by a 16-point Gaussian quadrature formula. The values of $B_{N-1}(t)$ for this integration were obtained from the previously constructed table of B_{N-1} by a modified Tchebycheff-Everett interpolation formula. Tables of $B_2(u)$ constructed by this method agreed with (39) (separately tabulated) to six decimals. For all $N \leq 8$, tables for the smaller values of Δ were consistent to four decimals for the entire range of u.

An additional check was provided. The function defined by (41) for all complex values of u is an entire function, which therefore admits a power series,

$$B_N(u) = \sum_{k=0}^{\infty} b_k{}^N u^k, \tag{77}$$

valid for all values of u, and which coincides with the desired distribution function for positive real values of u. It is not especially difficult to show that $b_k{}^N = 0$ for all odd k and for $k < 2N$. It can be shown on the basis of extensive computations from (41) that for even $k \geq 2N$,

$$b_k{}^N = (-1)^{k/2-N} \frac{2^{k/2}}{k!} \sum_{l=1}^{l=(k/2)+1-N} p_l \times \cdot \sum_{j_1+\cdots+j_{N-1}=k/2-l}^{j_i \geq 1} p_{j_1} p_{j_2} \cdots p_{j_{N-1}}, \tag{78}$$

where

$$p_l = (2l-1)(2l-3) \cdots 5 \cdot 3 \cdot 1. \tag{79}$$

In particular, the coefficient $b_{2N}{}^N$ of the leading term is $b_{2N}{}^N = 2^N/(2N)!$, *i.e.*,

$$B_N(u) = \frac{2^N}{(2N)!} u^{2N} + \cdots, \tag{80}$$

but this term alone is not sufficiently accurate for useful values of u. For larger values of k, (78), which has resisted strenuous attempts at simplification, is not as useful for the explicit computation of coefficients as the recursion relation

$$b_k{}^N = (-1)^{k/2-N} \frac{1}{k!} \sum_{j=1}^{j=(k/2)-1} 2^j p_j (k-2j)! \left| b_{k-2j}{}^{N-1} \right|, \tag{81}$$

which can also be established from (41). In connection with (81), one uses $b_k{}^1 = (-1)^{(k/2)-1}/(k/2)!$.

It can be shown from (78) that for $|u| \leq u_0$ and for

$$k \geq 2\left(N - 1 + \frac{1}{N}\right) u_0{}^2 - 2, \tag{82}$$

the terms of (77) are monotonically decreasing in magnitude. Since the terms alternate in sign, this means that the error in terminating (77) at the kth term is less than the magnitude of the kth term, provided (82) is satisfied. This was used to construct a table of $B_N(u)$ for $N = 2, 3, \cdots, 8$ for $0 \leq u \leq 1.5$ with a guaranteed accuracy of six decimals. This table agreed in this range with that constructed from (76) to six decimals or better.

The results (78), (81), and (82) are principally due to Michael Ginsburg.

Appendix V

Certain Questions Related to the Problem of Correlated Fading

All of the presently published treatments of correlated fading known to the present writer rely on a result due to Uhlenbeck,[42] which was reproduced in a paper by Booker, Ratcliffe, and Shinn.[43] Uhlenbeck's result rests in turn on the joint distribution of two Rayleigh variables given by Rice.[44] However, meaningful sufficient conditions under which this distribution is applicable to correlated Rayleigh fading do not appear to be known. It is essentially certain that it is applicable to narrow-band random noise of the type originally studied by Rice and Uhlenbeck, but it is far from clear that it is equally applicable to fading radio waves in general. For example, if Uhlenbeck's result always held, then the correlation of two Rayleigh variables could not be negative; however, several investigators, including Grisdale, *et al.*,[5] and McNicol[45] have found such negative correlation. It seems very probable that Uhlenbeck's result is satisfactory as a first approximation for engineering purposes. This is why Fig. 16 was unhesitatingly included in Section VII; however, such results should be understood as representative, rather than absolute. In other words, the correlation coefficient does not uniquely determine diversity performance, even when ρ and the separate input distributions are known.

A closely related problem that sometimes arises in this connection is the assumption, which has not always been recognized as such, that two random variables that are individually Gaussian or normal have a joint distribution that is a two-dimensional normal distribution. This assumption is the basis of the common statement that "uncorrelated normal variables are independent." As a mathematical matter, this need not be true; it is not difficult to give counter-examples. The prevalence of the quoted statement probably stems in part from some insufficiently explicit language of Cramér.[46] The two-dimensional form of the central limit theorem suggests that this assumption would often be very reasonable, but should be recognized as an assumption.

Appendix VI

Selection Diversity Mean Power Ratios

In the integral (17) for $\bar{p}(N)$,

$$\bar{p}(N) = N \int_0^{\infty} p(1 - e^{-p})^{N-1} e^{-p} dp, \tag{17}$$

we make the change of variable $y = 1 - e^{-p}$, obtaining

$$\bar{p}(N) = N \int_0^1 [-\log(1-y)] y^{N-1} dy. \tag{83}$$

[42] G. E. Uhlenbeck, Rad. Lab., M.I.T., Cambridge, Mass., Rep. No. 454; October 15, 1943.

[43] H. G. Booker, J. A. Ratcliffe, and D. H. Shinn, "Diffraction from an irregular screen with applications to ionospheric problems," *Phil. Trans. Royal Soc. (London) A*, vol. 242, pp. 579–607; September, 1950.

[44] S. O. Rice, "Mathematical analysis of random noise," *Bell Sys. Tech. J.*, vol. 24, pp. 46–156; January, 1945. See (3.7-13).

[45] McNicol, *op. cit.*, Fig. 4.

[46] Cramér, *op. cit.*, p. 289.

Using the series

$$-\log(1-y) = \sum_{k=1}^{\infty} y^k/k \text{ for } |y| < 1,$$

$$\begin{aligned}\bar{p}(N) &= N\int_0^1 \left[\sum_{k=1}^{\infty} \frac{y^{k+N-1}}{k}\right] dy \\ &= \sum_{k=1}^{\infty} \frac{N}{k(k+N)} \\ &= \sum_{k=1}^{\infty} \left(\frac{1}{k} - \frac{1}{N+k}\right) \\ &= \lim_{m\to\infty} \left[\sum_{k=1}^{m} \left(\frac{1}{k} - \frac{1}{N+k}\right)\right] \\ &= \lim_{m\to\infty} \left[\sum_{k=1}^{N} \frac{1}{k} - \sum_{k=1}^{N} \frac{1}{m+k}\right] \\ &= \sum_{k=1}^{N} \frac{1}{k}, \end{aligned} \tag{84}$$

which is the result (18). The termwise integration from the first to second line of (84) is easily justified.

The result $\bar{p}(N) = \sum_{k=1}^{N} 1/k$ was originally found essentially by accident and verified by induction on N.[47] Another direct approach was also suggested by Stein, who pointed out that (17) could be written

$$\bar{p}(N) = -\frac{\partial}{\partial x}\int_0^{\infty} N(1-e^{-p})^{N-1}e^{-xp}dp\,\Big|_{x=1}, \tag{85}$$

which, integrating by parts $(N-1)$ times, becomes

$$\bar{p}(N) = -\frac{\partial}{\partial x}\left[\frac{(x-1)!N!}{(x+N-1)!}\right]\Bigg|_{x=1}. \tag{86}$$

Stein remarked that this is

$$\bar{p}(N) = -N\frac{\partial}{\partial x}\beta(N,x)\,\Big|_{x=1} \tag{87}$$

where $\beta(N, x)$ is the Beta function [substitute $t = e^{-p}$ in (85)], and that higher moments of p are given by successive derivatives of the same function. The differentiation indicated in (86) is straightforward.

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I am also indebted to my colleagues W. C. Mason and Michael Ginsburg for the use of the equal-gain distributions in Figs. 9–13 before the complete tables of Mason, *et al.*, have been published. Phyllis Bloom and Marguerite Glynn of the Division 3 Computing Section of Lincoln Laboratory provided substantial assistance with the material in Appendix IV and prepared several of the curves.

[47] The procedure used here was suggested by one of the IRE reviewers.

Bibliography

The following list includes most of the theoretical papers related to diversity techniques published since 1947, together with two papers of historical interest. The comments following the references from [3] onwards are those of the present author and are not intended to be complete summaries of the papers involved. (Additional references dealing primarily with experimental results or instrumentation techniques are included among the footnotes.)

[1] H. H. Beverage and H. O. Peterson, "Diversity receiving system of RCA Communications, Inc., for radiotelegraphy," Proc. IRE, vol. 19, pp. 531–561; April, 1931.

[2] H. O. Peterson, H. H. Beverage, and J. B. Moore, "Diversity telephone receiving system of RCA Communications, Inc.," Proc. IRE, vol. 19, pp. 562–584; April, 1931.

[3] Z. Jelonek, E. Fitch, and J. H. H. Chalk, "Diversity reception, statistical evaluation of possible gain," *Wireless Engr.*, vol. 24, pp. 54–62; February, 1947. Selection diversity for the cases 1) uncorrelated Rayleigh fading and 2) partially correlated shallow Gaussian fading for two channels is analyzed. The first case is also considered at the low end of the distribution for unequal mean signals.

[4] A. H. Hausman, "An analysis of dual diversity receiving systems," Proc. IRE, vol. 42, pp. 944–947; June, 1954. A comparison of two-channel selection diversity and scanning diversity in terms of unspecified general fading distributions is presented but no concrete results.

[5] L. R. Kahn, "Ratio squarer," Proc. IRE, vol. 42, p. 1704; November, 1954. This is a note pointing out that two-channel maximal-ratio diversity could outperform two-channel selection diversity. Instrumentation and comparative tests are discussed.

[6] D. G. Brennan, "On the maximal signal-to-noise ratio realizable from several noisy signals," Proc. IRE, vol. 43, p. 1530; October, 1955. Statement and proof of the theorem are embodied in (13) and (14) of the present paper.

[7] H. Staras, "Diversity reception with correlated signals," *J. Appl. Phys.*, vol. 27, pp. 93–94; January, 1956. An ingenious method of evaluating the effect of partially correlated Rayleigh fading in two-channel selection diversity systems is presented with results that are also useful in measuring such correlation.

[8] F. J. Altman and W. Sichak, "A simplified diversity communication system for beyond-the-horizon links," IRE Trans. on Communications Systems, vol. CS-4, pp. 50–55; March, 1956. Several comparative results on selection, maximal-ratio and equal-gain diversity systems, including a demonstration that equal-gain systems perform almost as well as maximal-ratio systems in the presence of Rayleigh fading, are presented. The importance of this paper has not yet been widely recognized, perhaps because it is in a journal with a very limited circulation and is so concise that even experts have failed to appreciate its contents. Apart from the papers by Adams and Mindes, and Morrow, *et al.*, and a passing reference by Staras, it is not even mentioned in any of the following references of this paper.

[9] H. Staras, "The statistics of combiner diversity," Proc. IRE, vol. 44, pp. 1057–1058; August, 1956. Curves of the distribution functions for maximal-ratio diversity and a method of approximating very-long-term distributions of the local SNR are presented. This method would be most accurate for systems with a large number of channels. Combiner diversity here means maximal-ratio diversity. See the end of Section IV following (33) in this paper.

[10] J. N. Pierce, "Diversity Improvement in Frequency-Shift Keying for Rayleigh Fading Conditions," Air Force Cambridge Res. Center, Bedford, Mass., Tech. Rep. No. 56-117; September, 1956. Results applicable to certain types of binary signals and four combining methods, including maximal-ratio and selection diversity, are considered. See [15].

[11] K. H. Schmelovsky, "Einfluss der Korrelation zwischen Empfangsfeldstarken bei Diversity-Empfang," *Hochfrequenz. Elektr.*, vol. 65, pp. 74–76; November, 1956. (Translations of Friedman available at the John Crerar Library.) A method of evaluating the effect of partially correlated Rayleigh fading in two-channel selection diversity systems is discussed.

[12] F. E. Bond and H. F. Meyer, "The effect of fading on communication circuits subject to interference," PROC. IRE, vol. 45, pp. 636–642; May, 1957. An analysis of two-channel selection diversity for the case of Rayleigh-variable signals in Rayleigh-variable noise is presented. This case often arises in practice in communication systems operating at frequencies below 30 mc. This case was also considered for a selection diversity system in which the selection is of the channel with the greatest signal-plus-noise, in contrast to the greatest SNR.

[13] E. Henze, "Theoretische Untersuchungen über einige Diversity-Verahren," *Arch. Elekt. Übertragung*, vol. 11, pp. 183–194; May, 1957. (Translations by M. D. Friedman available from the John Crerar Library, 86 E. Randolph St., Chicago 1, Ill.) A consideration of two-channel selection diversity and scanning diversity, including both uncorrelated and partially correlated Rayleigh fading cases, is presented. Several of the derivations are extraordinarily complicated and can be greatly simplified.

[14] K. S. Packard, "Effect of correlation on combiner diversity," PROC. IRE, vol. 46, pp. 362–363; January, 1958. Combiner diversity here means maximal-ratio diversity. A method of estimating the effect of partially correlated Rayleigh fading in two-channel maximal-ratio diversity systems is discussed.

[15] J. N. Pierce, "Theoretical diversity improvement in frequency-shift keying," PROC. IRE, vol. 46, pp. 903–910; May, 1958. Error rates for various combining techniques are derived and the effects of correlated fading in dual-diversity binary systems are considered. See also additional references pertinent to binary signal systems given in this paper.

[16] R. T. Adams and B. M. Mindes, "Evaluation of IF and baseband diversity combining receivers," IRE TRANS. ON COMMUNICATION SYSTEMS, vol. CS-6, pp. 8–13; June, 1958. A comparison of predetection equal-gain combining with postdetection maximal-ratio combining for a two-channel FM system is presented, with a theoretical and experimental demonstration of the reduction in FM multipath distortion achieved by using predetection equal-gain combining.

Physical Principles of Avalanche Transistor Pulse Circuits*

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Summary—**A simple physical theory is developed which permits a calculation of the significant points of avalanche transistor transient behavior.**

A model for the transistor is defined in terms of charge variables and the physical parameters of the device. The transient performance of the model is calculated by focusing attention on the minority carrier charge stored in the base region and the influence of base-width modulation upon this stored charge. In the charge formulation of the problem, the physical details of the avalanche multiplication process need not be considered; multiplication is accounted for by the boundary conditions which it imposes upon the stored charge.

Good agreement has been obtained between calculated and experimentally observed data for a simple avalanche transistor relaxation oscillator.

I. INTRODUCTION

TRANSISTORS exhibiting avalanche multiplication have recently been shown[1] to be useful for the generation of millimicrosecond pulses. These devices thus provide a new and simple solution to a problem which previously taxed the ingenuity of both circuit and device designers.

As is frequently the case, however, a simple empirical solution poses difficult analytical problems. These analytical difficulties arise primarily from a failure to recognize the important physical principles which govern the terminal behavior of the device. When the problem is properly formulated, many of the analytical complications are removed, and a simple unified theory is obtained. It is the purpose of this paper to present such a theory.

The most significant aspect of the theory is the concept of minority carrier charge stored in the base region during the transient period, a concept which results in a considerable simplification of the problem by permitting time to be eliminated in several of the calculations.[2] A relaxation oscillator (Fig. 1) is used to illustrate the theory.

Section II of the paper deals with the circuit model for the relaxation oscillator, together with a physical model for the avalanche transistor; the concept of stored minority carrier charge is also introduced.

In Section III, the stored charge concept is used to determine the two critical values of external capacitance: the capacitance required to start regeneration and the capacitance required to forward bias the collector junction.

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[1] G. B. B. Chaplin, "A method of designing transistor avalanche circuits with application to a sensitive transistor oscilloscope," paper presented at 1958 Solid-State Circuits Conference, Philadelphia, Pa.; February, 1958.

[2] W. Shockley and J. Gibbons, "Theory of transient build-up in avalanche transistors," *Trans. AIEE (Commun. and Electronics)*, no. 40, pp. 993–998; January, 1959.

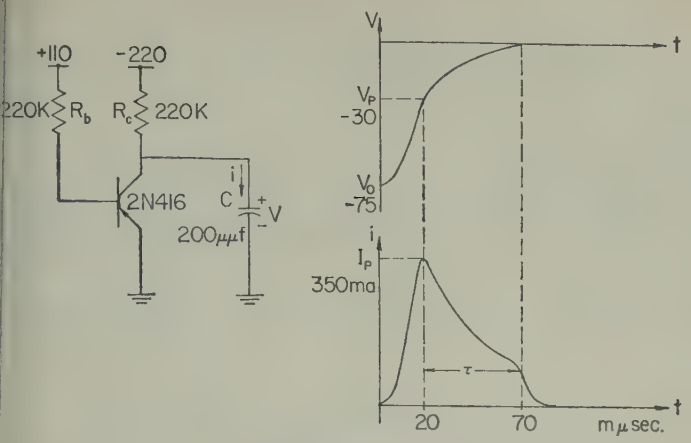

Fig. 1—Circuit and waveforms showing typical values for the avalanche transistor relaxation oscillator.

Section IV describes the detailed shape of the current pulse. Once again stored charge is used to calculate the peak current; a very simple method of approximating the rise-to-peak current is given; and the effect of base-width modulation is used to calculate the time after peak current required for the collector to become forward biased.

In Section V, observed values are compared with values calculated from the theory.

The significant results are:

1) The capacitance required to start regeneration varies inversely with the initial multiplication. However, the capacitance required to forward bias the collector junction depends critically upon the exponent n in

$$M = \frac{1}{1 - \left(\frac{V_c}{V_B}\right)^n}$$

and has a non-zero value even for infinite initial multiplication.

2) Regarding the detailed shape of the current pulse:
   a) The maximum current is a function of the minority carrier charge that has been stored when the effective multiplication reaches unity.
   b) The rise to peak current is approximately a short exponential rise followed by a linear rise. The exponential portion is given by the solution of the diffusion equation; a lower bound on the rate of rise of the linear portion is found by assuming the entire rise to be linear.
   c) The fall time is determined by the extent to which base-width modulation occurs. It is constant over a fairly wide range of capacitances.
3) The agreement between calculated and observed values is good in most cases. Adequate qualitative reasons can be given for existing departures.

II. The Avalanche Model

The operation of the relaxation oscillator is best visualized by assuming that the initial voltage across the capacitor is zero. The collector and emitter junctions are reverse biased with one or both junctions exhibiting avalanche multiplication. For simplicity it is assumed here that the emitter current is zero, only the collector junction exhibits multiplication, and the collector-to-base voltage is very nearly V_B, the breakdown voltage. Resistor R_c supplies the current required by the collector junction, and additional current to charge C negatively. As C charges, the collector to base voltage remains approximately V_B, so that when the voltage across C is V_B, the emitter junction becomes forward biased and injection into the base begins. It is at this time that the transient shown in Fig. 1 takes place. A regenerative action ensues during which the transistor-capacitor loop current builds up rapidly and the capacitor discharges. If the capacitor is not large enough, it will not be able to "bottom" the transistor; *i.e.*, drive the collector voltage to zero or forward bias.

In the circuit under consideration, the bias currents flowing in R_b and R_c are orders of magnitude smaller than the current in the transistor-capacitor loop during the period of interest. The function of these bias currents is merely to set the stage for the regenerative process; they contribute little to its actual development, and may therefore be omitted in studying the essential features of the transient build-up. The circuit model to be studied is shown in Fig. 2 and consists simply of a transistor and a capacitor.

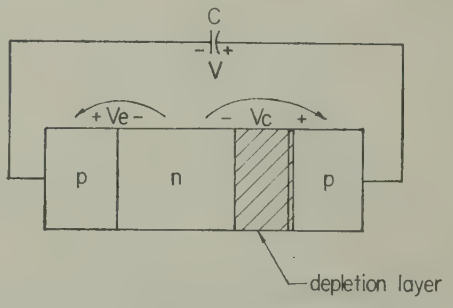

Fig. 2—Circuit model for the relaxation oscillator.

The plan of attack for the analysis of the circuit during the transient period is as follows: the transistor is represented by a diffusion model; *i.e.*, a model in which current flow in the base region is governed by diffusion of minority carriers. Four basic equations are then written in terms of charge variables for the diffusion model. These equations do not contain time. From these equations, the charge of minority carriers stored in the base region during the transient period is calculated. The stored charge is then used in the calculation of critical values of circuit capacitance, peak current, rate of rise, and fall-time.

General assumptions will be made to simplify the analysis. These are:

1) No carrier recombination occurs in the base during the time interval of interest.
2) Avalanche multiplication occurs only at the metallurgical junction and is described by the relation

$$M = 1/1 - \left(\frac{V_c}{V_B}\right)^n.$$

3) All of the voltage appearing across the load capacitor C appears across the collector depletion region; *i.e.*,

$$v_c \cong V, \qquad v_e \cong 0.$$

Under these conditions, a very simple physical model may be formulated for dealing with the detailed nature of the transients. The model is illustrated in Fig. 3. As is apparent from the figure, major emphasis is placed on charge variables. The following increments in the charge variables may be defined:

1) dQ is the incremental charge flowing in the external circuit.
2) dQ_s is the incremental charge of minority carriers stored in the base.
3) dQ_{mc} is the incremental charge of minority carriers arriving by diffusion at the base side of the depletion layer.
4) dQ_D is the incremental charge deposited in the collector side of the depletion layer.

With these definitions, the following equations may be written:

$$dQ_s = \gamma\, dQ - dQ_{mc} \tag{1}$$

$$M dQ_{mc} = dQ + dQ_D \tag{2}$$

$$dQ_D/C_c = dQ/C \tag{3}$$

$$dQ_{mc}/\gamma dQ \equiv \beta \tag{4}$$

where C_c is the collector capacitance and β is the transport factor under transient conditions for reverse collector voltage.

Eq. (1) expresses charge conservation in the base and relies for its validity on assumption 1); (2) expresses charge conservation in the depletion region; (3) is the result of assumption 3); and (4) is the definition of the transport factor.

These four simple equations are the basis of the theory to be developed.

III. Role of the Circuit Capacitance

As is implied in the introduction, the stored charge concept may be used conveniently to calculate certain capacitances which are critical in the operation of the relaxation oscillator circuit. The capacitances of interest are the minimum circuit capacitance required to start regeneration, C_R, and the minimum circuit capacitance, C_{min}, required to forward bias the collector junction

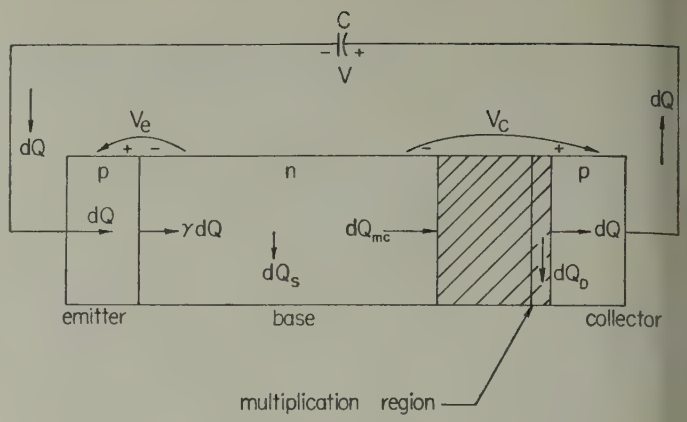

Fig. 3—Diffusion model showing charge variables for the avalanche transistor.

once regeneration is started. The calculation of these capacitances proceeds directly from (1)—(3), and does not require a consideration of time, a fact which results in considerable simplification of the analysis.

Using (2) and (3) to eliminate dQ_{mc}, (1) may be written as

$$dQ_s = \left(\gamma - \frac{1}{M_e}\right) dQ \tag{5}$$

where

$$M_e = \frac{MC}{C + C_c} \tag{6}$$

is called the effective multiplication factor.

It may be seen immediately from (5) that when

$$\gamma\, M_e = 1, \tag{7}$$

dQ_s is zero. It is possible that dQ_s may equal zero for M_0, the initial value of M, and, hence, no charge would ever be stored, and the regeneration process would never start.

It therefore follows from (7) that a circuit capacitance of

$$C \geq C_R = \frac{C_c}{\gamma M_0 - 1} \tag{8}$$

is required to start regenerative action.

Eq. (5) may also be used to calculate the "bottoming" capacitance C_{min}. This may be done by realizing that

$$M_e = \frac{CM(V)}{C + C_c(V)}$$

and

$$dQ = C dV$$

so that

$$Q_s = \int_{V_0}^{V} dQ_s = \int_{V_0}^{V} \left(\gamma - \frac{C + C_c(V)}{CM(V)}\right) C dV. \tag{9}$$

Assuming that the collector-base junction is a step transition from uniform p-type material to uniform n-type material, C_c may be written approximately as

$$C_c = C_{cB}(V_B/V)^{1/2} \tag{10}$$

where C_{cB} is the collector capacitance at the breakdown voltage. Using this and the form of M given in assumption 2),

$$Q_s = \frac{CV_B}{n+1}\left[\left(\frac{V}{V_B}\right)^{n+1} - \left(\frac{V_0}{V_B}\right)^{n+1}\right] - 2C_{cB}V_B\left[\left(\frac{V}{V_B}\right)^{\frac{1}{2}} - \left(\frac{V_0}{V_B}\right)^{\frac{1}{2}}\right] + \frac{2}{2n+1}C_{cB}V_B\left[\left(\frac{V}{V_B}\right)^{n+1/2} - \left(\frac{V_0}{V_B}\right)^{n+1/2}\right] + (\gamma - 1)C(V - V_0) \tag{11}$$

where V_0=initial voltage across C. The following reasoning is now used to obtain $C_{\min}$. When Q_s is zero, no current can flow in the circuit because there can be no minority carrier charge gradient in the base. There exists a minimum value of C which will make Q_s in (11) zero just when V, the capacitor voltage, becomes zero. This must be $C_{\min}$, the minimum value of capacitance required to forward bias the collector junction. Setting Q_s and V equal to zero in (11) and noting that in general $n>3$

$$C_{\min} \cong \frac{2C_{cB}}{\dfrac{(V_0/V_B)^{n+1/2}}{n+1} - (1-\gamma)\left(\dfrac{V_0}{V_B}\right)^{1/2}}. \tag{12}$$

An interesting case results if $V_0 = V_B$ and $\gamma = 1$:

$$C_{\min} \cong (2n+1)C_{cB}.$$

This shows that a non-zero value of $C_{\min}$ exists even when $M_0 = \infty$ ($V_0 = V_B$), and it depends critically on n.[3] A qualitative understanding of this is easily obtained by considering the behavior of M vs V/V_B for two extreme cases, $n=1$ and $n=\infty$. These are shown in Fig. 4. From (5) it is evident that the ratio dQ_s/dQ is never greater than $[1-(1/M)]$. For the case $n=\infty$, an infinitesimal change dV in voltage results in an M of unity and no charge is being stored. On the other hand, if $n=1$, some charge will be stored even when V/V_B is much less than 1. Thus it is expected that $C_{\min}$ will increase as n is increased.

IV. The Shape of the Current Pulse

In addition to its use in the calculation of critical capacitances, the theory embodied in (1)–(4) provides a convenient basis for obtaining the detailed shape of the current pulse. It should be pointed out that significant changes occur in the pulse as C is varied. In particular, if $C=C_{\min}$, the pulse is reasonably symmetrical about its maximum. If $C>C_{\min}$, the pulse assumes the shape given in Fig. 1. For extremely large values of C, the pulse may differ considerably from that shown, and for this case, the theory does not apply. For simplicity in the calculations of peak current, rise time, and fall time which follow, the second of these conditions ($C>C_{\min}$) will be assumed.

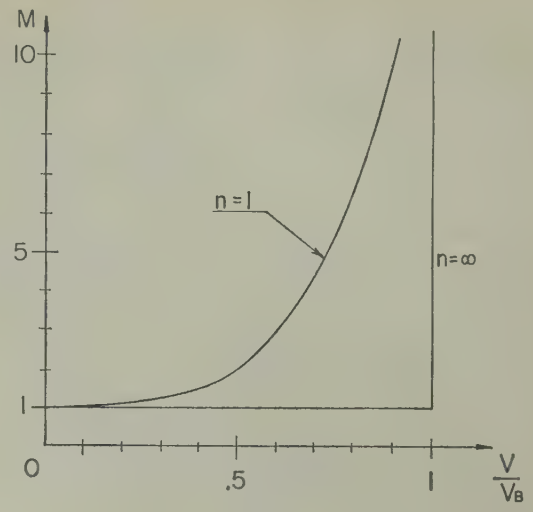

Fig. 4—Illustration of the dependence of M on n.

Calculation of the Peak Current

A solution of the diffusion equation shows that if the base width does not change during the rise-to-peak current, the charge distribution in the base will be very nearly linear at peak current. On the other hand, if the base width changes appreciably (as in the case of a transistor operating near punch through) the peak current will occur before the charge reaches a linear distribution. For simplicity, the first case, that of a linear charge distribution, will be assumed.[4] The calculation of peak current, then, involves finding the voltage at peak current, calculating the stored charge; and calculating its gradient. The charge distribution is shown in Fig. 5.

With the assumption of a linear distribution, the incremental stored charge dQ_s is zero at peak current. If dQ_s were positive, an increase in stored charge would cause an increase in the gradient and, hence, in the current; if dQ_s were negative, a decrease in stored charge would cause a decrease in the gradient.

Setting $dQ_s=0$ in (7), the multiplication M (which will be almost unity) is found to be

$$M = \frac{C + C_c}{\gamma C}.$$

[3] J. R. A. Beale, W. L. Stephenson, and E. Wolfendale, "A study of high-speed avalanche transistors," *Proc. IEE*, pt. B, vol. 104, p. 398; July, 1957.

[4] For the second case, the approximate distribution can be found from a diffusion equation solution.

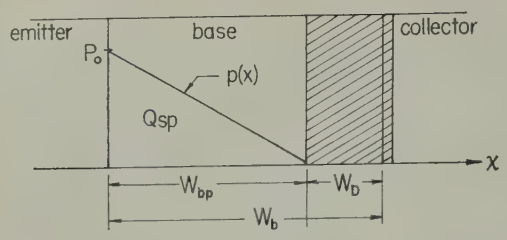

Fig. 5—Distribution of the stored charge at peak current.

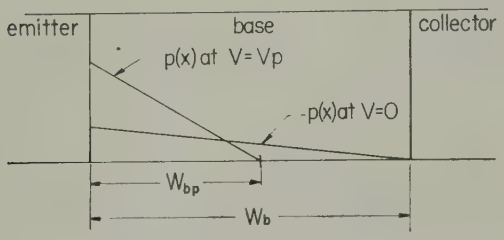

Fig. 6—Redistribution of stored charge after peak current.

If it is assumed that $C \gg C_c$, then $M = 1/\gamma$. The voltage V_p at peak current is found by using this result in the expression for M:

$$V_p = V_B(1 - \gamma)^{1/n}. \tag{13}$$

Thus far it has been assumed that no recombination is present. If recombination exists, the steady state value of the transport factor at peak current is β_0 and γ may be replaced by $\gamma\beta_0 = \alpha_0$.

As shown in Fig. 6, the base is assumed to be partially depleted, and the base width at peak current is denoted by W_{bp}. Since a step junction is postulated, W_{bp} is given by

$$W_{bp} = W_b - W_1\sqrt{-V_p}$$

where W_1 is the width constant of the junction.

Assuming that $C \gg C_c$, the minority carrier charge Q_{sp} which has been stored when the current reaches its peak value is obtained from (11):

$$Q_{sp} \cong \frac{CV_B}{n+1}\left(\frac{V_0}{V_B}\right)^{n+1}. \tag{14}$$

The peak current I_p is easily determined from the gradient of Q_{sp}:

$$I_p = \frac{2Q_{sp}D_e}{W_{bp}^2} \tag{15}$$

where D_e is the effective diffusion constant for minority carriers in the base.

(In many transistors sufficiently large currents exist when $C \gg C_c$ to make p_0, the minority carrier density at the emitter junction, much greater than the impurity density N_D in the base. An appreciable field exists into the base region, and causes the same effect as an increase in the diffusion constant. Thus

$$D_e \cong D\left(1 + \frac{p_0}{p_0 + N_D}\right) = 2D.)^5$$

The Rise to Peak Current

During the initial stages of current build-up, if the multiplication remains essentially constant, the current and charge variables will exhibit a time dependence of the form $\exp \lambda t$. Using (2), (3) and (4) of Section II, the relation

$$M_e\beta\gamma = 1 \tag{16}$$

may be obtained. It is to be emphasized that β is the transport factor for transient conditions. It has the form[6]

$$1/\beta = \cosh W\sqrt{\frac{\lambda}{D}}.$$

Substitution of (16) in the expression for β yields

$$\lambda = \frac{D}{W^2}(\cosh^{-1}\gamma M_e)^2.$$

When the multiplication varies during the current pulse (as it will for the relaxation oscillator), detailed analysis shows that the rise eventually becomes linear.[2] It is, in fact, observed that an appreciable portion of the current rise is linear. An estimate of a minimum value for di/dt during this linear portion can very simply be made by assuming a linear rise from zero to peak current. During the rise, the capacitor discharges from V_0 to V_p, and the total charge removed from the capacitor must be

$$Q = C(V_0 - V_p) = \frac{I_p^2}{2\dfrac{di}{dt}}. \tag{17}$$

Substitution of (14) and (15) into (17) shows that di/dt is directly proportional to C. This has been experimentally observed over a fairly wide range of values of C.

The Fall Time[7]

When the peak current occurs, minority carrier charge Q_{sp} is stored in the base and is linearly distributed. As the voltage across the capacitor changes, the base width increases, causing a redistribution of the charge. A solution of the diffusion equation shows that the charge distribution remains essentially linear because Q_{sp}

[5] See, for example, W. M. Webster, "On the variation of junction transistor current amplification with emitter current," PROC. IRE, vol. 42, pp. 914–920; June, 1954.

[6] W. Shockley and J. Gibbons, "Current build-up semiconductor devices," PROC. IRE, vol. 46, pp. 1947–1949; December, 1958.

[7] A similar approach has been used for punch-through transistors by H. Statz and R. A. Pucel, "The spacistor, a new class of high frequency semiconductor devices," PROC. IRE, vol. 45, pp. 317–324; March, 1957.

eaches its equilibrium distribution much more rapidly han changes in base width occur. In addition to the listribution of Q_{sp} remaining linear, the following assumptions are made in calculating the fall time:

1) $\gamma = 1$,
2) $C \gg C_c$. Thus the charge Q_D required by the depletion layer capacity is negligible in comparison to Q_{sp}, and Q_{sp} is conserved.

The change in voltage and the redistribution of charge re governed by

$$C\frac{dV}{dt} = I = \frac{2Q_{sp}D_e}{W(t)^2}. \tag{18}$$

If the collector-base junction is a step p-n junction,

$$W = W_b - W_1\sqrt{-V} \tag{19}$$

where W_1 = width constant.

A simultaneous solution of (18) and (19) gives the voltage as a function of time after peak current:

$$\left[W_b^2 V\left(1 - \frac{4}{3}\frac{W_1}{W_b}\sqrt{-V} - \frac{W_1^2}{W_b^2}\frac{V}{2}\right)\right]_{V_p}^{V} = \frac{2Q_{sp}D_e}{C}t. \tag{20}$$

The fall time, defined here as the time elapsed while the voltage changes from V_p to 0, is found by using zero as the upper limit of integration in (20) and using (14) for Q_{sp}:

$$\tau = \tau_b(n+1)\frac{V_p}{V_B}\left(1 - \frac{4}{3}x + \frac{x^2}{2}\right)\left(\frac{V_B}{V_0}\right)^{n+1} \tag{21}$$

where

$$\tau_b = \frac{W_b^2}{2D_e}$$

and

$$x = \frac{W_1\sqrt{-V_p}}{W_b}.$$

Eq. (21) indicates that τ is independent of C; Fig. 7 shows the range of values of C for which this is true. Qualitatively the variation of τ with C is explained as follows:

If the stored charge remains constant after peak current, the current fall will be determined by the variation of base width with time, and τ will have its minimum value which is given by (21). However, if the stored charge decreases with time, an additional decrease of current results and a longer time is required to discharge the capacitor.

For C only slightly larger than C_{min}, Q_D is not negligible in comparison to Q_{sp}, and the stored charge decreases causing, an increase in τ. If C is made very large, the emitter efficiency γ decreases, resulting in a reduction of stored charge and an increase in τ.

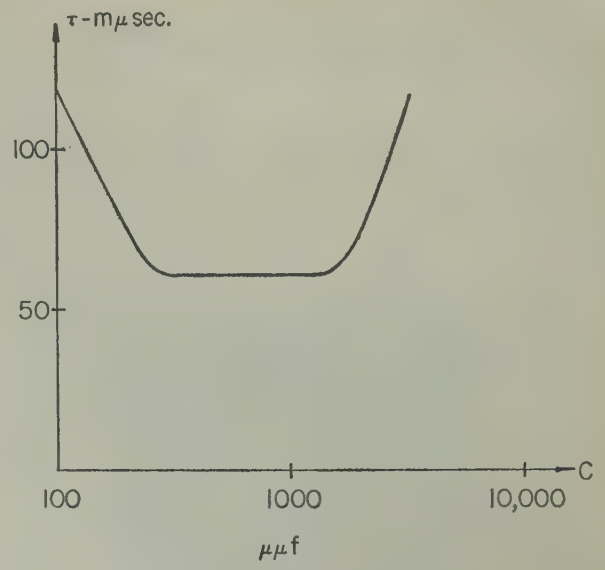

Fig. 7—Experimentally observed variation of fall time with external circuit capacitance.

V. "The Proof of the Pudding . . . "

The ultimate test of any physical theory is, of course, its agreement with observation. Before discussing the experimental results, however, it is worthwhile to comment briefly on the more important aspects of the theory.

It is significant that for circuit analysis, the complex physical details of the avalanche multiplication process can be simply represented as follows:

1) Multiplication occurs instantaneously and only at the metallurgical junction.
2) It is dependent only upon the junction voltage, in accordance with the empirical static multiplication relation.

Elimination of the details of the multiplication process thus permits the formulation of the problem in terms of charge variables, with multiplication serving only to determine boundary conditions. The result is the simple and straightforward theory just presented.

Table I gives the quantities V_B, n, C_c, α_0, W_b and W_1 which must be known for the transistor in order to make the calculations shown in Table II. These quantities were obtained as follows:

1) W_b and W_1 were calculated from values of alpha cutoff frequency measured at several values of reverse collector voltage.
2) V_B was obtained from the voltage-current characteristic of the collector diode measured with a low duty cycle sawtooth voltage waveform.

TABLE I

PARAMETER VALUES USED FOR CALCULATIONS

Transistor	$W_b \times 10^3$ cm	$W_1 \times 10^3$ cm/V$^{1/2}$	V_B volts	n	$C_c \mu\mu f$ at $V_c = 1$v	$(1-\alpha_0)$ at $V_c = 1$v $I_c = I_p$	V_0 volts
2N416-1	1.62	0.10	−76	4.7	19	0.091	−66
2N416-2	1.48	0.085	−80	4.6	21	0.043	−56
GT762-1	0.80	0.060	−30	4.75	30	0.0091	−29
GT762-2	0.75	0.057	−31	4.1	35	0.011	−28

Table II compares observed and calculated values for the circuit of Fig. 1, with $C = 200$ $\mu\mu$f. The deviations which occur are considered to be attributable primarily to experimental inaccuracies, except in the cases of rate of rise and fall time.

Concerning rate of rise, calculated value is intended only to be a lower bound on the linear portion of di/dt. Since the entire current rise is not linear, calculated value is expected to be less than the measured value.

TABLE II

CALCULATED AND MEASURED VALUES FOR CIRCUIT OF FIG. 1, $C = 200$ $\mu\mu$f

Transistor Type	$-V_p$		I_p ma		τ mμsec		C_{min} $\mu\mu$f		$1/\lambda$ mμsec		di/dt ma/mμsec	
	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured	Calculated	Measured
2N416-1	37	36	230	250	50	70	80	93	8	8	5.5	8
2N416-2	34	40	41	47	—	—	400	420	24	26	0.5	0.63
GT762-1	10	8	370	330	7.8	10	58	63	1	—	13	20
GT762-2	9.2	8	320	310	5.7	8	105	100	1.4	—	12.5	22

3) n was obtained by making pulse measurements, at a current of 10 ma, of the transistor α and the voltage $V_{\alpha M}$ at which $M\alpha$ was unity. $(1-\alpha)$ was assumed to be proportional to W^2, and the equation

$$M\alpha = \frac{\alpha}{1 - \left(\frac{V_{\alpha M}}{V_B}\right)^n} = 1$$

was solved for n.

4) C_c was measured for several values of reverse collector voltage to check its dependence upon $(-V)^{-\frac{1}{2}}$.

5) α_0 was measured at a collector voltage of -1 volt and collector current equal to the measured value of I_p. The voltage dependence of α_0 was found by assuming that $(1-\alpha_0)$ was proportional to W^2. (The value of α_0 at $V_C = -V_p$, $I = I_p$ was used for γ in the calculation of C_{min}. V_p was calculated by solving the equation $M(V)\ \alpha_0(V) = 1$ for V).

Furthermore, it is to be expected that the measured value of fall time τ will be greater than the calculated value, for the following reasons:

1) At the high currents which are obtained, the emitter efficiency γ is less than unity and stored charge is being lost through the emitter. Thus the current is decreased and τ is increased.
2) As the stored charge is redistributed, the field in the base may be reduced. The result is a decrease in D_e, hence a reduction of τ.
3) The charge Q_D required by the depletion layer capacity is not negligible. This reduction in stored charge has the same effect as a non-unity emitter efficiency.

VI. ACKNOWLEDGMENT

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Pulse Amplification Using Impact Ionization in Germanium*

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Summary—Some aspects of the phenomena of impact ionization an impurity doped semiconductor at 4.2°K are described. The ization time is shown to be a strong inverse function of the elec- field. Control of the breakdown process is used to obtain pulse plification in the millimicrosecond range, using two- and three- minal devices. These devices are inherently stable, very simply nstructed (requiring only ohmic contacts), and have easily manage- le dimensions.

In controlling the breakdown process, a small amount of control wer or energy applied at an *early* time determines the course of an alanche-type buildup so that at a *later* time a substantial change in wer or energy level is affected. Although other rise time control plifiers are known (*e.g.*, the super-regenerative vacuum tube plifier), the present amplifier is believed to be the first solid state vice which operates on this principle.

Peak power and current gains on the order of 20 have been ob- ined for 25 and 50 mμsec pulses. It also appears that voltage gain possible under somewhat different operating conditions than have en examined to date. The lower limit for pulse length in these ex- riments was determined by measurement equipment limitations ther than by any device limitation.

Introduction

IMPURITY-TYPE semiconductors can attain very high resistivities at sufficiently low temperatures. Such behavior is due to the decrease in the number mobile carriers available. Most of these carriers be- me reattached to the impurity atoms when the ther- al energy, kT, becomes considerably less than the im- urity activation energy, ϵ_i. In general, the remaining rriers may have very high mobilities at such low tem- eratures. Therefore, the carriers (either holes or elec- ons) can acquire kinetic energy rapidly from rather nall electric fields applied to the crystal. When they ve attained energies $>\epsilon_i$, there exists the possibility an ionizing inelastic collision with a neutral impurity om. This results in more carriers becoming available r conduction. In fact, the current rises very steeply hen the applied electric field is increased beyond the itical value needed to initiate the ionization. This ef- ct is called impact ionization of impurities in the semi- nductor.[1] It is analogous to a gaseous discharge in any respects. A typical current-voltage characteristic shown in Fig. 1. The voltage V_B is designated as the reakdown voltage.

In germanium, the critical field is about 10 v/cm at 2°K. Previous experiments[2] with heavily doped Ge had revealed that the current rise time is in the 10^{-9} sec range once the critical electric field is exceeded by about 50 per cent. The recombination process was also found to be in the 10^{-9} sec range for the crystals examined. Two results in those experiments suggested the possibility of constructing a pulse amplifier based on impact ionization. They were:

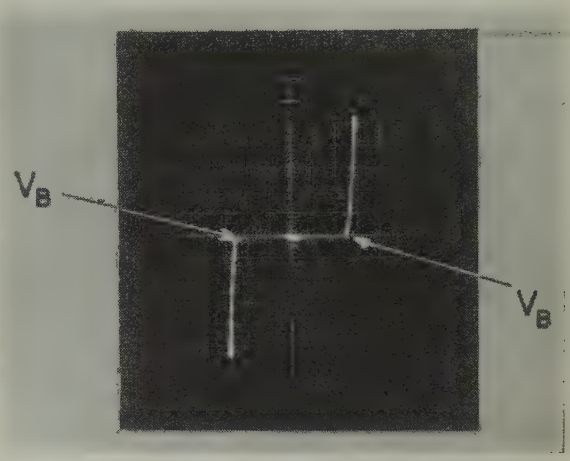

Fig. 1—Typical current-voltage characteristic; V_B is the breakdown voltage. Ordinate = 20 ma/cm; abscissa = 5 v/cm.

1) The current rise time decreased rapidly as the applied electric field was increased above the critical value.

2) The current rise time decreased when the germanium was exposed to visible radiation.

The first of these results is readily understood in terms of the model[1] for explaining the impact ionization effect. The time needed for a carrier to gain the amount of energy required to produce ionization would certainly be an inverse function of the strength of the applied electric field. Precise measurements of the rise time as a function of electric field were not made in the previous[2] work. One of the objects of the present work was to study this effect in detail. In fact, the results of such measurements form the major basis of most of the material that follows in this report.

The second result is not easily understood in all its aspects. From the fact that light creates additional carriers which themselves can then contribute to the ionization process, it would follow that a given current level would be attained at an earlier time (all other factors being the same). However, experiments currently in progress indicate that the critical electric field, itself, decreases when germanium is exposed to visible light. Clearly such an effect would also be important in determining the rise time of the current.

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[1] N. Sclar and E. Burstein, "Impact ionization of impurities in rmanium," *J. Phys. Chem. Solids*, vol. 2, pp. 1–23; January, 1957.
[2] M. C. Steele and G. B. Herzog, unpublished report.

In light of these experiments, two types of pulse amplifiers were considered. The first is based on modulating the electric field over part of the germanium by means of a third electrode placed between the input and output terminals. All the contacts to the germanium would be *ohmic* in such a device. Another way of modulating the rise time in a two-terminal device is to alter the input pulse shape by means of a control signal. Such a diode can also give amplification under proper operating conditions. Both the two- and three-terminal devices were built and studied in detail. The results are discussed in this paper. It should be noted here that in the three-terminal device there is no isolation between the control signal source and the drive source. In this sense, the device differs from conventional amplifiers. The second type of pulse amplifier depends on being able to introduce light pulses on the germanium, thereby modulating its conductivity over a wide range. There are a number of interesting possibilities in such devices. Some of the possible uses for these and other impact ionization devices will be discussed in the conclusion of this report.

Experimental Details

All the crystals used in these experiments were *n*-type germanium. The room temperature resistivities varied from 0.1 to 1 ohm-cm. A typical wafer, using ohmic line contacts, is shown in Fig. 2. The side contact was located either midway between the two end contacts, or near the end from which the output was taken.

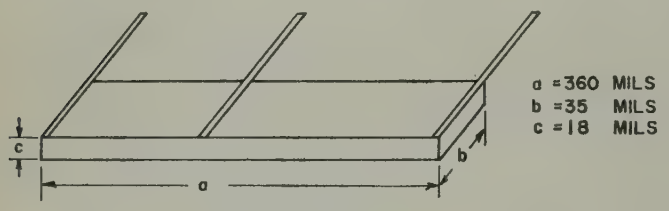


Fig. 2—Typical wafer dimensions.

Measurements were made with the wafer immersed in liquid helium at 4.2°K. Coaxial wires, supported within an inconel tube, were connected to the wafer as shown in Fig. 3. Connection was made to the side contact through a 7K resistor. Time delay effects in comparing signals at the three wafer contacts were eliminated by using "output" cables of equal length at the drive, control, and load terminals of the wafer, in addition to the cables for applying the drive and control signals (Fig. 3). The "output" cables were terminated in their characteristic impedance.

Amplification and current rise time measurements were made using pulses ranging from 10 to 100 mμs in length and from 12 mv to 200 v in amplitude. The rise and fall times of the applied pulses were about 1 mμs. Voltage measurements were made on an oscilloscope

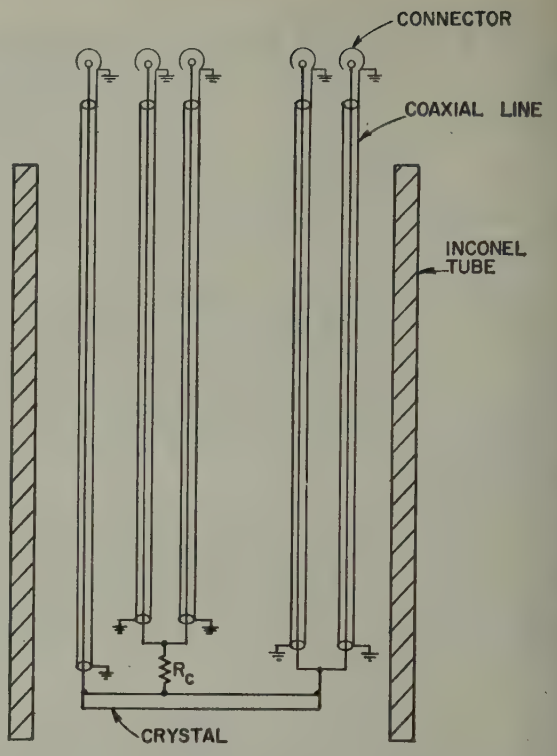


Fig. 3—Structure used to insert crystal in the liquid helium dewar showing the coaxial line connections to the crystal.

having a 7-mμs rise time to square pulses and a maximum sensitivity of 0.1 v/cm.

The current-voltage characteristics at high current levels were obtained with the use of another pulse generator. This unit supplied a 40-μs pulse at a pulse repetition frequency of 130 cps. The pulse amplitude was varied at a 60 cps rate. As viewed on an oscilloscope, the current-voltage characteristic appeared as a series of moving points which photograph as a smooth curve. A typical characteristic obtained in this way is shown in Fig. 1. For more accurate voltage-current measurements at low direct current levels (down to 10^{-10} amperes), an electrometer type meter was used.

Discussion of Operation

Current Rise Time

The entire basis of the impact ionization amplifiers to be described below is that the current rise time can be strongly influenced by the magnitude of the applied electric field. Previous work[2] had only established qualitatively that the current rise time decreased as the electric field increased. In light of the fundamental importance of this functional relation in all the devices, it was studied in detail, experimentally. Before discussing the results of such experiments, a simple theoretical development of what might be expected will be given. The kinetic energy gained in a time t by a carrier moving in an electric field is:

$$\epsilon = e\mu E^2 t, \qquad (1$$

ere ϵ=energy, e=electronic charge, μ=carrier mo-
ty, and E=electric field. When $\epsilon \geq \epsilon_i$, the impurity
ivation energy, inelastic ionizing collisions can take
ce to produce more mobile carriers. It follows from
that τ_0, the minimum time needed to produce car-
multiplication, is

$$\tau_0 = \frac{\epsilon_i}{e\mu E^2} \cdot \tag{2}$$

e simple derivation of (2) does not take into account
changes in mobility as the carrier gains energy. In
ual crystals, the mobility will change with energy in
vay determined by the dominant type of scattering.
twithstanding this simplification, (2) gives a func-
nal relation that is germane to the device operation.
points out the fundamental nature of the electric
d effect on the current rise time.

Experiments to verify the general nature of (2) were
formed at 4.2°K with an n-type germanium wafer
ving a resistivity of 0.6 ohm-cm at 300°K. Pulses of
) mμs width and varying amplitudes were applied to
e crystal. The output across a 75-ohm series resistor
s applied directly to the plates of the oscilloscope.
ider these conditions, the oscilloscope rise time was
out 2 mμs and the vertical sensitivity was 11 v/cm.
e time, τ, required for the output current to reach
out 15 ma (well below saturation) was noted for each
ltage. Results of such measurements are given in Fig.
where τ is plotted as a function of voltage on a log-log

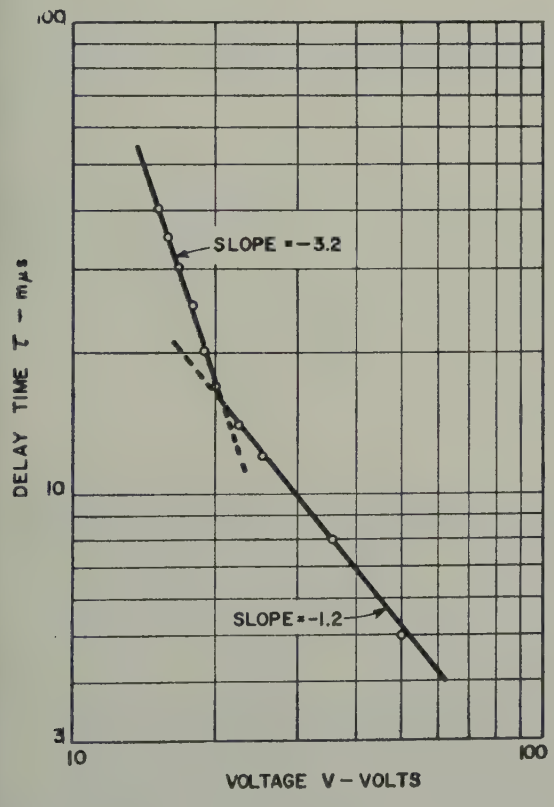


Fig. 4—Current delay time vs applied voltage, sample IIA-2.

basis. For low electric fields, it is found that $\tau \propto 1/E^{3.2}$, while at higher fields $\tau \propto 1/E^{1.2}$. It follows therefore that (2) is obeyed qualitatively. The deviation of the experimental results from (2) are most likely associated with, a) the simplification made in the mobility, and b) the variation of the cross section for an ionizing collision with the energy of the carrier. Since the purpose of the present work is to utilize the τ vs E dependence in understanding device operation, a detailed comparison of Fig. 4 to theory was not pursued. It properly forms the basis of further fundamental studies in the phenomenon of impact ionization.

Signal Amplification

Diode Operation: The results shown in Fig. 4 suggest that properly chosen means for influencing the amplitude or phase of a voltage pulse by a control signal might result in amplification. From the viewpoint of simplicity of analysis the first case considered is a diode structure with the crystal itself as the load. Referring to Fig. 5, a drive voltage pulse of amplitude V_D and duration $(t_D - t_c)$ is applied to the crystal in the absence of any control signal. The control signal is a voltage pulse of amplitude V_c and precedes the start of the drive pulse by a time t_c. The duration of the control signal pulse is also t_c. The amplitudes of both V_c and V_D *must exceed* the breakdown voltage, V_B. During the time interval 0 to t_c it is assumed that the current is rising exponentially[3] with time according to the equation

$$I = I_0 \exp(t/\tau_2), \tag{3a}$$

where I_0 is the initial current just before the onset of breakdown and τ_2 is the time constant characteristic of the voltage V_c. With no control signal present the current rise in the interval t_c to t_D is

$$I = I_0 \exp \frac{t - t_c}{\tau_1}, \tag{3b}$$

where τ_1 is associated with V_D. When the control signal is present, the current rise in the interval t_c to t_D is

$$I = I_0 \exp\left(\frac{t_c}{\tau_2}\right) \exp \frac{t - t_c}{\tau_1} \cdot \tag{3c}$$

It then follows (see Appendix) that the energy gain produced by the control signal is

$$K = \frac{\Delta\epsilon}{\epsilon_{in}} = 1 + \left(\frac{V_D}{V}\right)\left(\frac{\tau_1}{\tau_2}\right)\left[\exp\left(\frac{t_D - t_c}{\tau_1}\right) - 1\right]. \tag{4}$$

In (4), ϵ_{in} is the input energy of the control source, and $\Delta\epsilon$ is the net change in the output energy during the time interval 0 to t_D. It is seen that for a fixed t_D, the energy gain is maximized for $t_c = 0$. When $t_c = t_D$ the gain is unity.

[3] A good approximation at low currents. Exponential behavior is expected in the absence of strong three-body interactions.

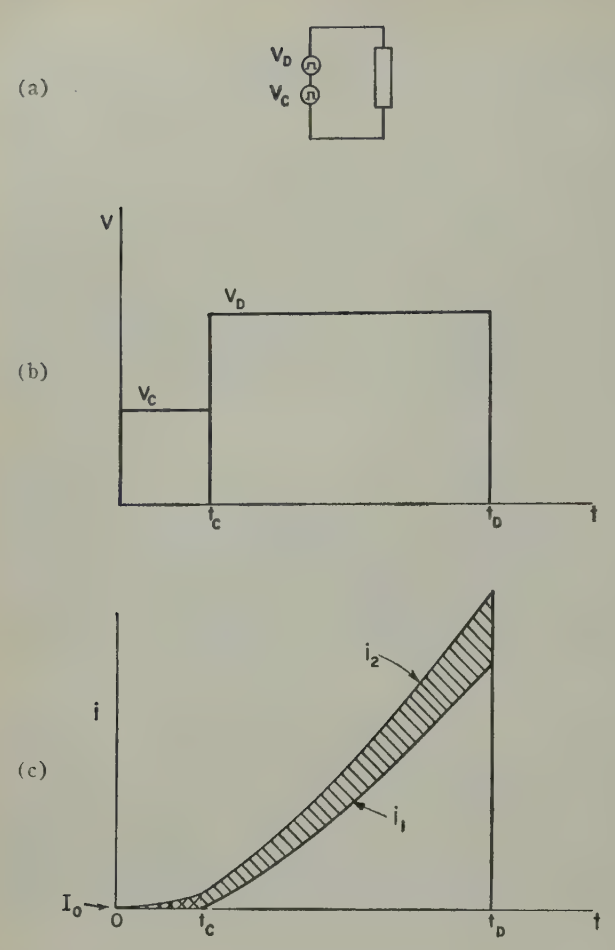


Fig. 5—Pulse time modulation method for energy gain in a diode. (a) Circuit. (b) Applied voltage vs time. (c) Diode current vs time; i_1 is the current when no control voltage is applied; i_2 is the current when control voltage is present.

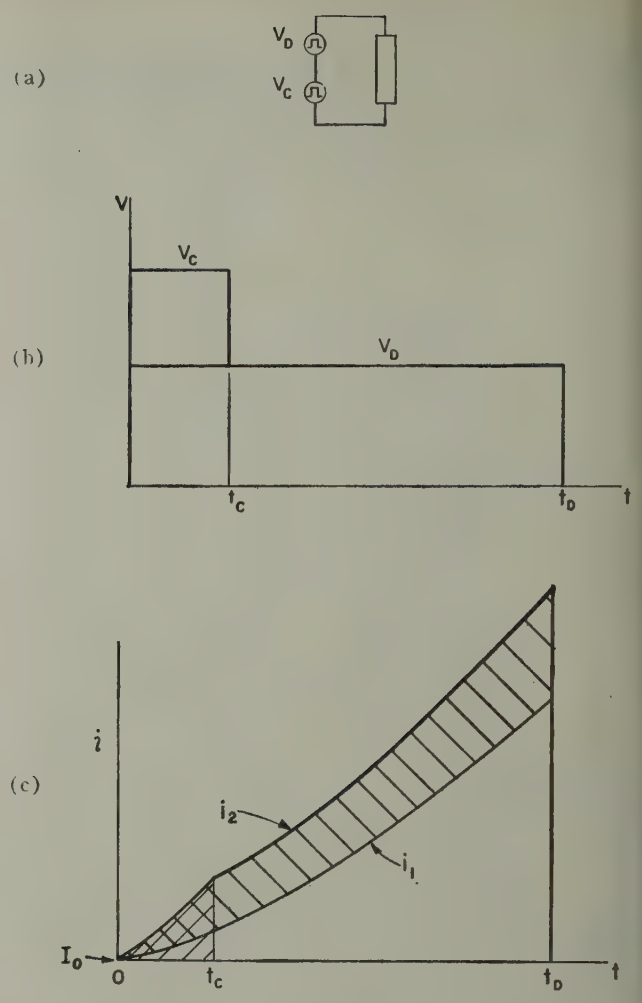


Fig. 6—Pulse amplitude modulation method for energy gain in a diode. (a) Circuit. (b) Applied voltage vs time. (c) Diode curren vs time. i_1, i_2 are as defined in Fig. 5.

Energy gain can also be obtained by superposing a short control signal of amplitude $V_c - V_D$ for a time interval of t_c on a longer drive voltage of duration t_D. Such a situation is depicted in Fig. 6. In this case the energy gain is

$$K = 1 + \frac{\left(\frac{V_D}{V_c}\right)\left(\frac{\tau_1}{\tau_2}\right)\left[\exp\left(\frac{t_c}{\tau_2}\right)\left\{\exp\left(\frac{t_D - t_c}{\tau_1}\right) - 1\right\} - \left\{\exp\left(\frac{t_D}{\tau_1}\right) - 1\right\}\right]}{\left\{\exp\left(t_c/\tau_2\right) - 1\right\}} . \quad (5$$

If an external resistive load is put in series with the impact ionization diode shown in either Fig. 5 or Fig. 6, the analysis becomes complicated. The resulting expression for the current is a transcendental function whose argument is itself a function of the current. No attempt was made to seek a solution for this case.

Triode Operation: It is clear that any means of influencing the electric field in the impact ionization device might result in amplification. A triode configuration with a side contact (control) placed between the input (drive) and output (load) ends is shown in Fig. 7. Here, the drive amplitude is sufficiently large to produce an output across the load in the absence of a control voltage. The potential values along the device are depicte in Fig. 8 as the current in the unit builds up from zero t the final value in the load resistor. Fig. 8(a) shows th potential distribution at the instant the positive driv

pulse is applied. Since the crystal resistance is then ver large compared to the control circuit resistance, th contact C is essentially at ground potential. As soon a some current (carrier multiplication) begins to flo from D through C to ground, the potential at C begin to increase with respect to point L (which is still a ground potential). The difference in potential betwee C and L finally reaches (or exceeds) the breakdown volt age for that section of the crystal. That situation shown in Fig. 8(b). Now current flows through the ex ternal load resistor causing the potential at L to in crease. This is shown in Fig. 8(c) at the instant the driv pulse is terminated.

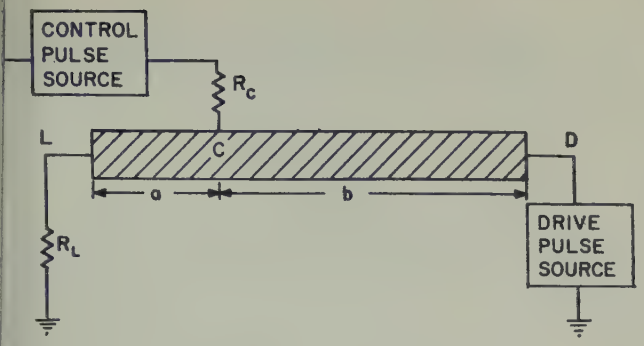


Fig. 7—Basic circuit of triode amplifier.

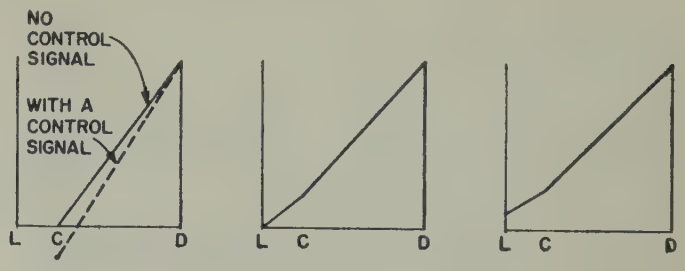


Fig. 8—Potential diagram of triode amplifier. (a) At instant when voltage is applied to the crystal. (b) When side contact reaches the breakdown voltage for region *C-L*. (c) When drive pulse is terminated.

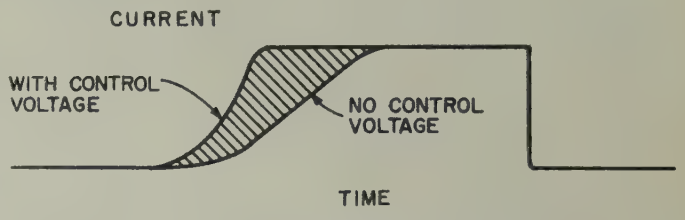


Fig. 9—Effect of control voltage on load current.

By introducing a control signal of opposite polarity to e drive, the breakdown in section *D-C* is accelerated ce the electric field between these two points has been reased. This is depicted by the dotted line in Fig. a). Because of this action, the section *C-L* also breaks wn earlier causing a higher average load current to w during the drive pulse. The control pulse is termited before the end of the drive pulse. Details of the ration of the control pulse will be given later. If the ve pulse were on long enough to produce saturation the load current, the difference in load current with d without the signal would be as shown in Fig. 9. No ange would be made in the saturation current, but the erage current would be greater when the control pulse s present. It follows similarly that if the drive and ntrol pulses were of the same polarity, the average curnt would be smaller with the control present.

This qualitative description of the triode operation ows clearly that any possible amplification must oc- during the *time of rise* of the current. In this sense, e device is a "rise-time controlled amplifier." The aded area in Fig. 9 represents the integrated (current) (time) increase resulting from applying the control nal. For greater efficiency of operation, the drive lse duration should be less than that required to proce saturation of the load current. Under these conditns, the peak power gain, K_p, can be defined as

$$K_p = \frac{\Delta P_0}{P_c}, \tag{6}$$

ere ΔP_0 is the change in peak power output resulting m applying the control signal of peak power P_c. For s circuit (Fig. 7)

$$\Delta P_0 = \frac{1}{R_L}\left[(V_{L2})^2 - (V_{L1})^2\right], \tag{7}$$

ere V_{L2} and V_{L1} are the peak load voltages with and thout a control signal, and R_L is the load resistance. thin the framework of the limits to be set forth below e instantaneous value of P_c, the input power, will be ined as

$$P_c = V_c I_c, \tag{8}$$

where V_c is the control voltage and I_c is the current in the control source. Clearly I_c will vary with time during the presence of the control signal. It must start from zero and increase monotonically (perhaps approaching a saturation value). Hence, in general, the input power is

$$P_c = \frac{V_c(V_x + V_c)}{R_c}, \tag{9}$$

where R_c is the resistance in series with the control circuit and V_x is the potential at point C of the crystal. In (9) it is assumed that the control voltage is $-V_c$. With the control and drive present, and before any current flows in the device, $V_x = -V_c$. The maximum value that V_x can attain is dictated by the position of the side contact relative to the drive and load ends. Referring to the dimensions shown on Fig. 7, that value is

$$(V_x)_{\max} = \left(\frac{a}{a+b}\right)(V_D - V_{L2}) + V_{L2}. \tag{10}$$

Note that the control pulse could be turned off before V_x reaches the value of (10) without affecting the output current. In fact, the control pulse does not contribute to the amplification after V_x exceeds the value of zero. From this criterion, the duration of the control pulse can be ascertained experimentally from the observed current rise time characteristics as a function of electric field. It follows that for optimum operation, the control pulse should be of shorter duration than the drive pulse. The maximum useful *peak* value of P_c is then given as

$$P_c = \frac{V_c^2}{R_c}. \tag{11}$$

Eq. (11) does not necessarily give the value of P_c needed to maximize the power gain. The calculation of that

value is complicated by the details of how the output varies with time for a given drive pulse.

In actual use, the energy gain per operation is of importance. This would be obtained by integrating (7) and (9) over the appropriate time intervals of drive and control duration respectively.

The power gain definition given by (7) and (8) is a very general one in that the net power output is considered to be the *change in output power* due to the input signal. It is important to distinguish that definition from the one conventionally used in the analysis of devices.[4] In the more conventional definition, the useful output power is defined in terms of the *change in output voltage* (or current) due to the input signal. By this criterion, the power gain would be defined by

$$K_p' = \frac{\frac{1}{R_L}(V_{L2} - V_{L1})^2}{V_c I_c}. \tag{12}$$

Eq. (12) implies that information is carried by the voltage in excess of a residual or carrier voltage rather than by the power in excess of a residual power. It is seen, however, that the values of K_p and K_p' become identical when $V_{L1}=0$. For all other values of V_{L1}, $K_p > K_p'$.

There are several ways to make V_{L1} negligibly small compared with V_{L2} in the impact ionization amplifier. The first one would be to make the drive pulse duration short enough to insure that $V_{L1} \ll V_{L2}$. Such a direction is also the most desirable for fastest possible operation. The second way would be to have a dc bias present at the control terminal of such a polarity as to cut off the pulse output when no control signal is applied. This would be analogous to biasing the grid of a tube to cutoff. In the present situation, the bias potential would be be the *same sign* as the drive pulse potential, while the control pulse would be of opposite polarity.

Although the power gain definition given by (12) is the conventional one, the use of (7) and (8) to define power gain presents a more fundamental description of the impact ionization amplifier.

Results

Direct Current Control Signals

The general ideas of triode operation were first tested with direct current control signals and pulsed drive. Fig. 7 shows the circuit used for this purpose except that the control pulse source was replaced with a dc source. A 25-mμs positive pulse of fixed voltage was applied to the crystal. The output current into the 75-Ω load was measured. Then dc was passed from point *C* through the 75 Ω load and the effect on the output pulse was noted. Fig. 10 shows a sketch of the results. Trace *a* is the pulse current when no dc was applied. Trace *b* is the pulse current when +0.2 μa of dc flowed from point *C* through the output load to ground. Trace *c* is the pulse current for −0.2 μa of dc. It is seen that a very small amount o dc was able to affect a large charge in the output puls current. If a current gain, K_I, is defined as

$$K_I = \frac{\Delta I_L}{I_{dc}}, \tag{13}$$

where ΔI_L is the net change in the *pulse* output curren and I_{dc} is the dc current, it is found that $K_I \simeq 10^4$ for th results shown in Fig. 10.

The observed changes in output pulse current ar brought about by changing the electric field betwee points *D* and *C* when the dc is applied. In fact, thes observations conform with the explanation offere above for the triode operation. The polarity of the ap plied voltage on point *C* can cause an increase or de crease of pulse output since the rate of rise of the cur rent is a function of the electric field. The large value of current gain merely emphasize that the control i *field* dependent rather than current dependent. In thi respect an arrangement, such as shown in Fig. 10, ma be very useful for measuring small currents in hig impedance circuits.

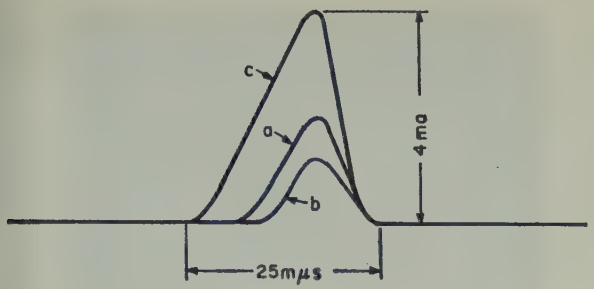
Pulsed Control Signals

If the dc source is replaced by a signal pulse sourc the operation allows one pulse to control the other (se Fig. 7). The mechanism would then be exactly as de picted in Fig. 8 and Fig. 9 for the triode amplifier. Fo a positive drive pulse, a positive control pulse should de crease the output current, while a negative control puls should increase the output. These anticipated result were verified experimentally. A typical result for a nega tive drive and a positive control pulse is shown in Fig 11. Trace *a* is the output current pulse for a *negativ* drive pulse with *no control* pulse applied. Trace *b* is th output current pulse for a *positive* control pulse with n drive pulse applied. Trace *c* is the output current puls when the same applied pulses for traces *a* and *b* ar *simultaneously* applied to their respective terminals From Fig. 11 it is seen that a current input of 0.67 m has produced a change in output current of 5.3 ma.

Triode Power Gain with Pulsed Control Signals

Power gain into a load resistor was demonstrate using the circuit shown in Fig. 12. The transformer i the control circuit inverts the polarity of the contro pulse relative to the drive pulse. For these tests, both th drive and control pulses were 50 mμs long. With th definition of P_c given in (9) the results are shown in Fig 13. For these data, V_x was taken as the value given b (10). Actually V_x could have been smaller than the va ues calculated in this way, but the resulting maximu differences in P_c would only be about 20 per cent les than the values shown in Fig. 13. It is seen that pea power gain was exhibited. In particular, the power gai becomes greater as the drive pulse amplitude is in creased and the control pulse is decreased. Such a resul

[4] The authors wish to thank T. O. Stanley for bringing this matter to their attention.



ig. 10—Output pulse for circuit in Fig. 7, but with side contact pulse source replaced by a dc source.

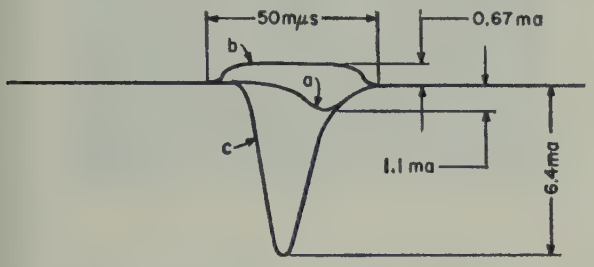


Fig. 11—Output pulse for circuit in Fig. 7.

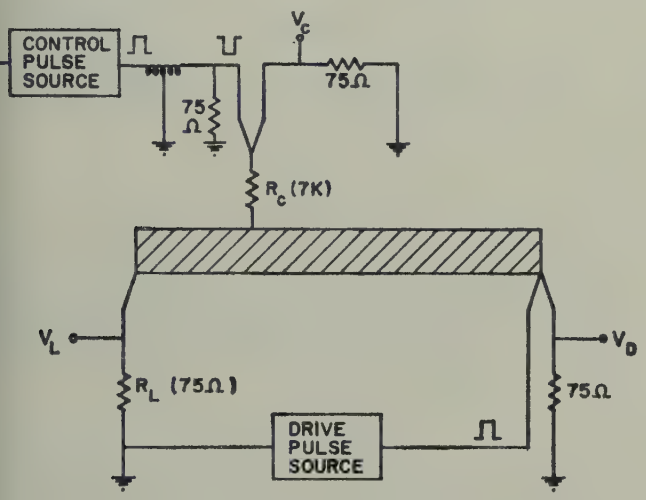


Fig. 12—Circuit for measuring peak power gain of triode amplifier.

oints to the fact that such an amplifier would be most eful for *very short* drive pulses of high amplitude. It is visioned that in such cases the device could give amification for pulse lengths of 1 mμs. The oscilloscope nitation in rise time prevented operation in this range short pulses.

It was pointed out above that the control pulse need ot be as long as the drive pulse. In fact, for optimum *ergy* gain per drive pulse, the control pulse should be orter. To demonstrate this feature an experiment was rformed with a drive pulse of 50 mμs and a control ulse of 20 mμs. For $V_D = 20$ v, the resulting input and tput powers were the same as those shown in Fig. 13 here the control pulse was 50 mμs long). Such a result in conformance with the description of the operation ven above. Actually the control pulse does not con-

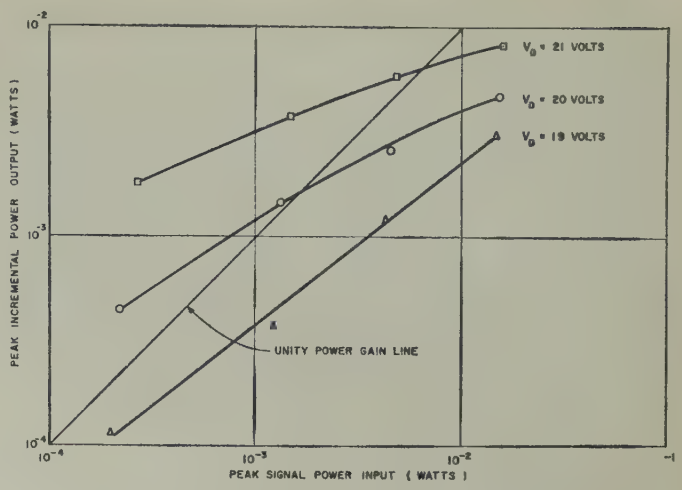


Fig. 13—Peak incremental power output vs peak signal power input, obtained using (7) and (9).

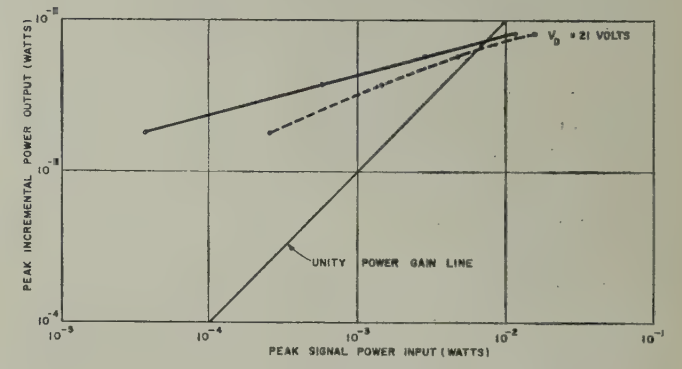


Fig. 14—Peak incremental power output vs peak signal power input using (7) and (11). The dashed curve is shown for comparison, and is obtained from (7) and (9).

tribute to the amplification after $V_x = 0$ (see discussion of triode operation). Since this gives the maximum necessary length of the control pulse, the theoretical power input could be less than the values shown in Fig. 13. In Fig. 14, the results for $V_D = 21$ v are given as the solid curve for P_c calculated according to (11). The dotted curve in Fig. 14 shows the comparative data for $V_D = 21$ v calculated according to (9). It is seen that the solid curve gives higher power gains over the entire range. The maximum value of power gain in Fig. 14 was 17 db, and occurred with the smallest input power.

In order to complete this discussion, it is important to note that the alternative definition of power gain, (12), gives lower values than those deduced from Fig. 13 and Fig. 14. The reason for the lower values is that V_{L1} was not zero in the experiments performed to date. As mentioned earlier in the text, V_{L1} could be minimized by using either a shorter drive pulse or a dc bias on the control terminal. However, analysis of the *existing* data by means of (11) and (12) gives a power gain of 2.4 db for the smallest input power shown in Fig. 14. This should be compared with the value 17 db when the output power for the same point was calculated according to (7).

Diode Power Gain with Pulsed Control Signal

The circuit shown in Fig. 6 was altered to include a series load resistor (75 ohms). With this circuit energy gain into an external load was demonstrated. The actual input and output pulse forms are shown in Fig. 15. From these data, the input and output energies were computed. The resulting input energy was 1.1×10^{-10} watt-sec, while the net output energy was 2.4×10^{-9} watt-sec; this corresponds to an *energy* gain, K_ϵ, of 22. Such a result confirms, qualitatively, the analysis leading up to (4) and (5), and points to the potentially important use of two-terminal impact ionization devices.

Discussion

Use of Amplifier

In general, the experimental results confirm the models described for the operation of the two terminal and three terminal impact ionization amplifiers. There are specific comments that can now be made about the use of the three-terminal devices. To begin with, it can be used as a fast current amplifier. This suggests the possibility of counting nuclear events very rapidly. Such use would be most efficiently realized if the low currents were associated with a high impedance source.

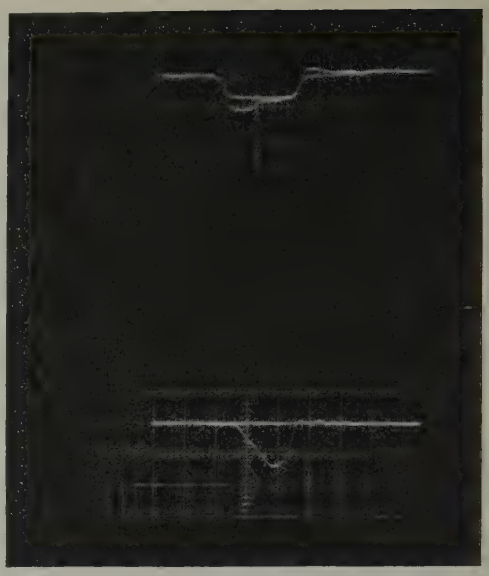
Because current gain is so readily attained, the device could be used to drive low impedance current sensitive loads. Superconducting memory elements fall into this class. The concept of controlling a transient condition forms the basis of the work described in this report. Such a concept may be extended to other transient phenomena that involve sharp nonlinearities in a current-voltage relation.

Voltage Gain

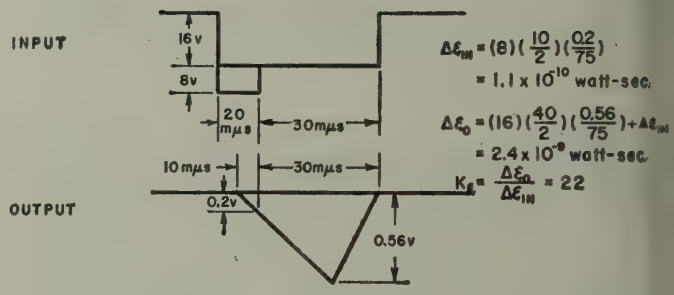
The possibility of driving one impact ionization amplifier with another leads to the question of voltage gain. For most of the experiments performed thus far, the measured voltage gain has ranged from 0.01 to 0.1, with the larger value corresponding to a higher drive voltage. The voltage gain was relatively insensitive to changes in control voltage. Since impact ionization devices are *field* sensitive rather than current sensitive, voltage amplification is necessary for one unit to drive another. Several possibilities present themselves for controlling one unit from the output voltage of another unit.

The most obvious solution to the multistage drive problem (in the absence of voltage gain) is to use pulse coupling transformers to step up the output voltage. However, since the transformer must be located at the germanium crystal (to avoid loading effects of the connecting transmission lines), this raises the problem of finding a core material that would be suitable at liquid helium temperatures. At present, no such material is available.

A second method is to connect a large resistor directly to the output terminal of the crystal, and couple this point to the control terminal of the next crystal. This avoids the low impedance limitation imposed on the



(a)



(b)

Fig. 15—Energy gain in a diode amplifier. (a) Typical input and output waveforms. Upper photo shows input voltages; ordinate = 20 v/cm, abscissa = 20 mμs/cm. Lower photo shows output voltage across 75 Ω load; ordinate = 0.4 v/cm, abscissa = 20 mμs/cm. (b) Simplified representation of input and output waveforms, and calculation of energy gain.

previous voltage gain measurements by the transmission line characteristic impedance (75 ohms). Some preliminary measurements have been made using this technique. In one test, a voltage gain on the order of 1.8 was obtained, but equipment limitations resulted in an uncertainty of about 50 per cent. Further, this limitation also prevented testing under the most optimum conditions. In a second preliminary test, one unit was made to control the output of another. There appears to be no inherent reason why voltage gain should not be attained. One approach for further work is to use a large load resistor at the output terminal of the crystal, and to use higher drive voltages (which would also result in faster operation).

Comparison with Super-Regenerative Amplification

The impact ionization amplifier is characterized as a rise time controlled device. This bears some resemblance to the operation of the super-regenerative amplifier familiar to radio engineers. In this type of amplifier, an oscillator is periodically turned off by means of a "quench" voltage. The time required for oscillations to

ld up when the quench voltage is removed depends whether the oscillations are initiated by the inherent ɔe noise or by an externally applied signal. The oscillans reach saturation earlier when a signal is applied, us changing the average plate current amplitude. The ration of the ON time (no quench voltage) determines ether the oscillations will reach saturation (logarithc mode) or be turned OFF by the quench voltage be-e saturation (linear mode).

The mode of operation of the impact ionization amplir described here may be better understood by comrison with the linear mode super-regenerative amplir. However, there is an important difference in the te of rise; *i.e.*, the time constant in the exponential ildup expression. For the super-regenerative receiver, is is a constant determined by the lumped constant rameters of the equivalent RLC circuit, and is indendent of the signal voltage. For the impact ionization ıplifier, on the other hand, the rate of rise is a strong verse function of signal voltage, as shown by (2) and g. 4. Despite this, it is felt that this comparison serves relate the operation of a new device to a familiar one.

Appendix

iode Analysis

Referring to Fig. 5, the input signal energy is

$$\epsilon_{in} = V_c \int_0^{t_c} I dt, \tag{14}$$

ıere I is given by (3a) in the text. Carrying out the tegration gives

$$\epsilon_{in} = V_c I_0 \tau_2 \left[\exp\left(\frac{t_c}{\tau_2}\right) - 1 \right]. \tag{15}$$

With no control signal present, the output energy is

$$\epsilon_0 = V_D \int_{t_c}^{t_D} I dt, \tag{16}$$

where I is now given by (3b). This integration yields

$$\epsilon_0 = V_D I_0 \tau_1 \left[\exp\left(\frac{t_D - t_c}{\tau_1}\right) - 1 \right]. \tag{17}$$

With control signal present, the output energy is

$$\epsilon_1 = \epsilon_{in} + V_D \int_{t_c}^{t_D} I dt, \tag{18}$$

where I is now given by (3c). The integration of (18) gives

$$\epsilon_1 = \epsilon_{in} + V_D I_0 \tau_1 \left[\exp\left(\frac{t_D - t_c}{\tau_1}\right) - 1 \right] \cdot \left[\exp\left(\frac{t_c}{\tau_2}\right) \right]. \tag{19}$$

From (14), (16), and (18) it follows that

$$K = \frac{\Delta\epsilon}{\epsilon_{in}} = \frac{\epsilon_1 - \epsilon_0}{\epsilon_{in}} = 1 + \left(\frac{V_D}{V_c}\right)\left(\frac{\tau_1}{\tau_2}\right)\left[\exp\left(\frac{t_D - t_c}{\tau_1}\right) - 1 \right]. \tag{20}$$

Eq. (20) is the value of K given by (4) in the text.

Acknowledgment

The authors wish to thank G. B. Herzog and E. O. Johnson for profitable suggestions throughout the course of this work.

The Transpolarizer: An Electrostatically Controlled Circuit Impedance with Stored Setting*

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Summary—**This new device operates by the controlled transfer polarization through two or more ferroelectric dielectric sections series and therefore is named "transpolarizer."**

It represents a new basic means for storing and gating electrical signals and, in general, means to control circuit impedance in any predetermined manner according to a stored setting.

The operation of a two section transpolarizer is described.

The unique storage, switching, and control properties of the transpolarizer open a large field of new applications and permit production of new devices and systems such as: recording and reproducing of intelligence in general and, more particularly, switching with a permanent setting, small and large scale storage devices with nondestructive readout, decoders, function generators, etc.

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THE transpolarizer,[1,2] analogous to its magnetic counterpart, the transfluxor,[3] consists of at least two capacitors with a preferable crystalline ferroelectric dielectric and a nearly rectangular hysteresis loop. Control of polarization transfer through two or more ferroelectric dielectric sections in series represents a new basic means for storing and gating electrical signals and, in general, a means for controlling circuit impedance in any predetermined manner according to a stored setting.

Non-linear "impedance" of a circuit at a given frequency can be set to any predetermined level by a single pulse, and it will remain for a long period of time. Therefore transmission of an ac power can be controlled or set to a desired level by a single setting pulse. This level may assume any value between zero and the maximum limits of the device, and an on-off or continuous stored control operation is possible.

Although various multisection transpolarizer arrangements have been operated and tested only the basic two section transpolarizer is described below. This basic circuit element shows good efficiency of power transmission, short setting time, negligible coupling between setting and output circuits and sharp setting thresholds.

Introduction

Recent material developments in ferroelectrics[4,5] with nearly rectangular hysteresis loops result in new storing and switching devices. Ferroelectric amplifier-choppers, gates, logical devices, bistable and astable multivibrators shift registers and memory matrices became practical. The use of ferroelectrics until now was limited because of fatigue effects and lack of a sharp threshold field.[6] These problems have been resolved. The new materials such as tri-glycine sulfate (TGS) and tri-glycine fluoberyllate (TGFB) do not have fatigue, and the threshold problems have been solved by a combination of semiconductors and ferroelectrics.[6] The basic element in all of these devices is a condenser with ferroelectric dielectric. When two or more ferroelectric capacitors form a common section or sections and polarization of the condensers can be individually controlled, interesting new switching and storing functions can be achieved.

The controlled transfer of polarization through ferroelectric sections of dielectrics suggested its name, "Transpolarizer." The transpolarizer can be regarded as a capacitor with a dielectric of variable dielectric constant to permit any setting of impedance in a continuous way between the blocked and unblocked states with a single setting pulse or bias, depending on circuit requirements. Any state once set will maintain its nonlinear impedance until another state is set. The transpolarizer is a voltage device with a short setting time, and when energized by an ac voltage, the current through it will correspond to its set impedance level. When operated in its blocked or unblocked states, it represents a storage element with "non-destructive" readout which permits construction of storage devices with permanent memory.

The unique high-impedance input feature of the transpolarizer renders it readily adaptable for control with an electron beam or photoelectric cell, and, as a result, such new devices as large display screens,[7] new visual pickup devices, combined ferroelectric and magnetic devices, etc., become feasible.

This paper presents the basic operation of the transpolarizer and will discuss its features as a circuit element.

Basic Operation

If two ferroelectric elements are connected in series and if the polarization vectors of both elements are identical, as shown in Fig. 1(a), the two series-connected elements exhibit electrical behavior identical to a single ferroelectric element.

If both elements have identical properties, a low-frequency hysteresis loop will be observed which has a coercive voltage of $2V_c$ and a total switched charge of Q_s.

If the polarization vectors of the two elements are in opposite directions, as shown in Fig. 1(b), the two-terminal device has strikingly different electrical properties from that of a single ferroelectric element. When a positive voltage—say a step function of finite rise time—is applied between the two external terminals, no net switching of charge results and the device resembles a normal linear dielectric capacitor. This can be explained with the aid of the low-frequency hysteresis loops of Fig. 1(b). As the applied voltage rises, it is at first equally divided between both elements. At a certain value of applied voltage, the upper element starts to switch, *i.e.*, the instantaneous value of charge starts to move around the lower knee of the hysteresis loop. At this point, the dielectric constant increases and therefore the capacitance of the upper element takes on a large value. Consequently, the applied voltage is no longer equally distributed across both elements but is divided in inverse proportion to its capacitances.

As applied voltage increases, voltage across the lower

[1] C. F. Pulvari, USAF Prog. Rep. No. 11, Contract No. AF 33(616)-2934; January, 1957.

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[4] R. Pepinsky, Y. Okayo, and F. Jona, "Ferroelectricity and structure of tri-glycine fluoberyllate and its isomorphs," *Bull. Am. Phys. Soc.*, ser. II, p. 220; 1957.

[5] C. R. Pulvari and W. Kuebler, "Polarization reversal in tri-glycine fluoberyllate and tri-glycine sulfate single crystals," *J. Appl. Phys.*, vol. 29, pp. 1742–1746; December, 1958.

[6] C. F. Pulvari, USAF Tech. Rep. No. 58-657, Contract No. AF 33(616)-2934.

[7] E. A. Sack, "A new electroluminescent display," 1958 IRE National Convention Record, pt. 3, pp. 31–39.

nent increases and the instantaneous value of charge ves in the saturation region of the hysteresis loop. this reason, the upper element cannot be switched the voltage on it remains constant at a value slightly than its coercive voltage. Thus, no switching results. polarity of applied voltage is reversed, the role of per and lower element interchanges. Since no switch- takes place, a straight line, which is characteristic of ar capacitors, will be observed in place of the nor- l hysteresis loop.

f no switching occurs, the two elements are said to in a "blocked" condition; if switching can take place, two elements are said to be "unblocked."

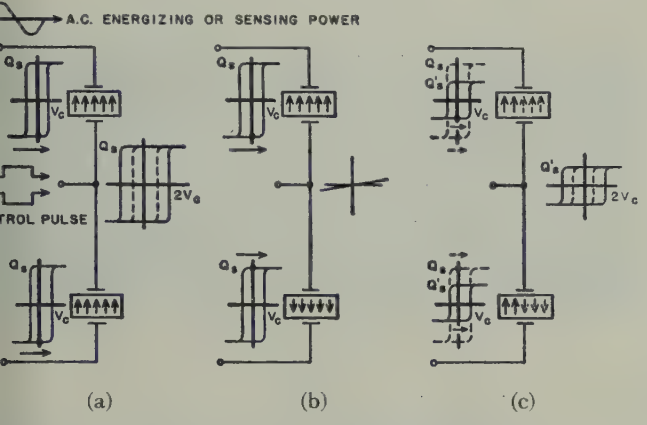

Fig. 1—Various states of a transpolarized: (a) unlocked state; (b) blocked state; (c) partially blocked state.

Fig. 1(c) shows a partially blocked state. This is ob- ned when the polarization of one of the capacitors is rtially switched from state *a* into state *b*, thereby ving part of the polarization vectors in both elements ntical. As a result, part of the polarization behaves cked (as indicated by the dotted arrows) and only t part of the polarization contributes to the loop ich is unblocked and can be freely switched. Coercive ltage will be again $2V_c$ but the switched charge Q_s' is s than Q_s in the completely unblocked state. It is ar that the partially blocked state *c* represents a ver capacitance than the unblocked state *a*, and that y level of partial blocking can be obtained depending the control signal applied as indicated in Fig. 1 which n be either a single pulse or a dc bias depending on ether a static or dynamic operation is required.

The most interesting feature of the transpolarizer is at it can be changed from a ferroelectric capacitor o a linear-capacitor and can assume any intermediate larization level between these two limits; further- ore, it is capable of controlling a flow of ac electric wer according to its setting.

These novel switching and storage features spurred erest to determine the behavior of the transpolarizer its blocked, partially blocked, and unblocked states as ll as its features as a circuit element.

The Blocked State

In order to investigate this state, the circuit shown in Fig. 2 was used. Again a two section transpolarizer comprising two identical ferroelectric storage cells connected in series was used. Actually, a twin storage cell was evaporated on a small single crystal of TGFB. The energizing ac or sensing signal will or will not produce a signal output in form of ac or transient as shown in Fig. 2 depending upon the setting pulse which may be a block or unblock pulse. The setting pulses are supplied through double anode saturation diodes as shown in Fig. 2 in order to isolate the setting pulse source from the circuit itself.

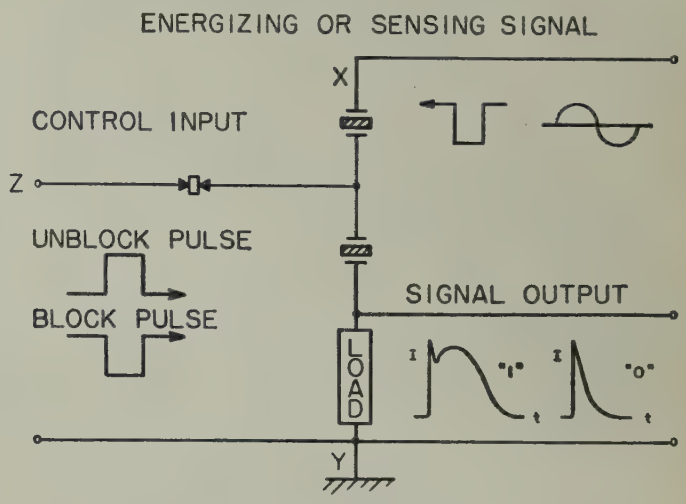

Fig. 2—Basic circuit of a transpolarizer.

Assuming a blocked state it was important to see how stable this state is when a) the energizing ac or sensing signal voltage increases, and b) a certain energizing voltage acts for a longer period of time.

Fig. 3 presents the variation of polarization, $\Delta P/P_s$ as a function of applied energizing voltage for various degrees of blocking. P_s is the saturation polarization. It is shown that a transpolarizer with a coercive voltage of $V_c = 17$ v does not change the blocked states, *i.e.*, ΔP is practically zero up to about 10 times its coercive voltage (170 v) and that to introduce a slight change starts at 200 v which increases to a value of $\Delta P/P_s = 1.2$ per cent at 400 v. When the energization potential is reduced to zero, a remanent change of 0.2 per cent was observed. This process could be repeated many times, and with each repetition, the remanent change increased by an additional 0.2 per cent. It is noted, however, that when the energizing voltage was only 170 volts and this was reduced, no change could be measured.

Fig. 4 shows $\Delta P/P_s$ as a function of time, for energizing voltages of 50, 150 and 400. It is again apparent that about one and one-half hours were needed for ef-

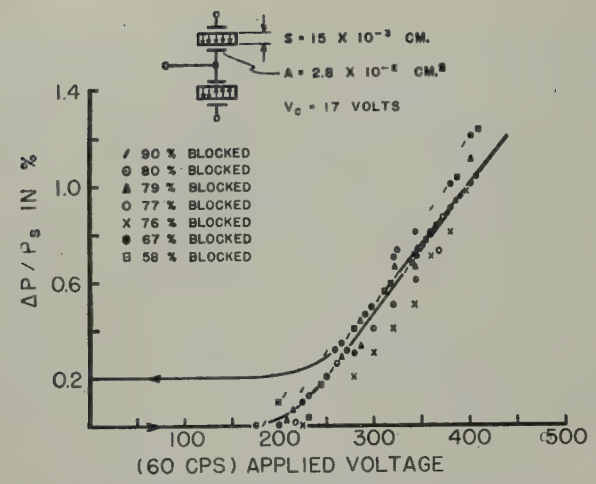

Fig. 3—The effect of energizing voltage on various blocked states.

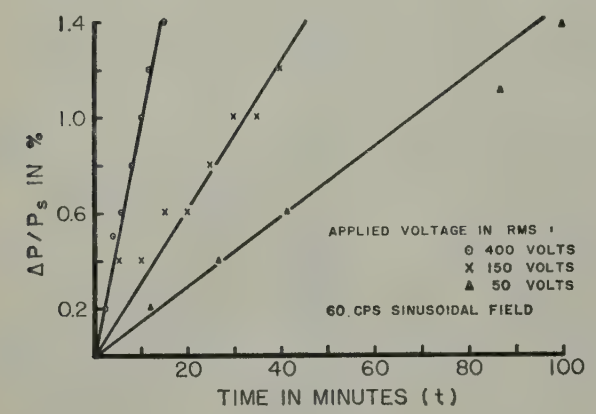

Fig. 4—Stability of the blocked state as a function of time.

fecting a remanent change of 1.4 per cent with a voltage three times the coercive voltage. As an illustration, it is noted that the number of switching cycles during this time was 325,000 with a 60 cps energizing voltage.

Fig. 5 gives the rate of change of polarization in function of applied energizing voltage.

These measurements show that the blocked state is quite stable and that it is difficult to force a change in this state.

The Unblocked State

This state has been discussed in connection with the illustrations in Figs. 1(a) and 1(c). The polarization of the unblocked state can be reversed. It then behaves like a normal ferroelectric condenser.[8] For determining the behavior of the unblocked state, pulse measurements were used. The plot given by circles in Fig. 6 is a plot of reciprocal switching time $1/t_{max}$, which is the switching time pertaining to the maximum value of the

[8] C. F. Pulvari and W. Kuebler, "A phenomenological theory of polarization reversal in $BaTiO_3$ single crystals," *J. Appl. Phys.*, vol. 29, pp. 1315–1321; September, 1958.

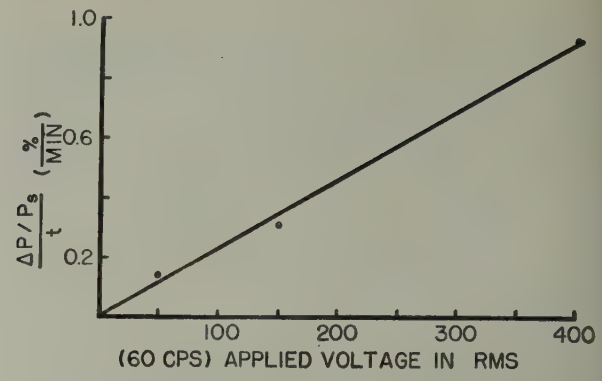

Fig. 5—Rate of change of polarization $\Delta P/P_S$ as a function of applied energizing voltage for the blocked state.

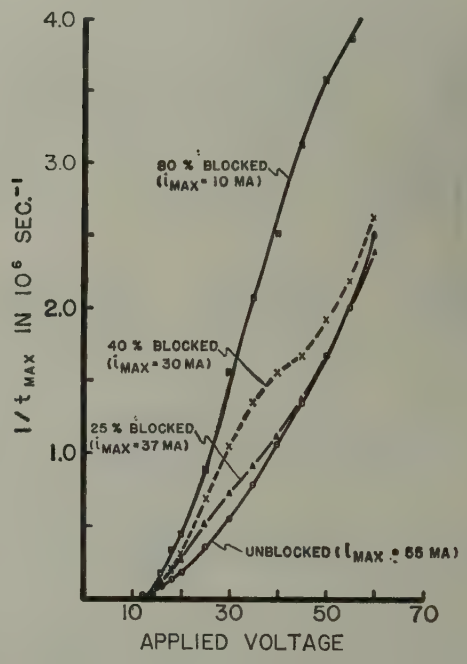

Fig. 6—Switching time characteristic of the unblocked state.

current transient i_{max}, vs applied pulse amplitude (in this case $i_{max} = 55$ ma). The coercive voltage V_c was 18 v for the unblocked state. The plots given by the measured points in triangles, crosses and squares pertain to 25 per cent, 40 per cent and 80 per cent blocked states, which leave unblocked 75 per cent, 60 per cent and 20 per cent, respectively. The maximum values of the current transients i_{max} were decreasing as 37, 30, and 10 ma corresponding to the decreasing fractions of unblocked polarization. These plots revealed an interesting change in the switching behavior, namely, the slope of the plots increase with increase of blocked-, and decrease of unblocked-polarization. This means that, in the partially blocked state, switching proceeds faster than in the unblocked state, and the mobility of domains increases. While the mobility increases, the coercive voltage V_c decreases. Fig. 7 shows the variation of V_c/V_{cs} (where V_{cs} corresponds to the completely un-

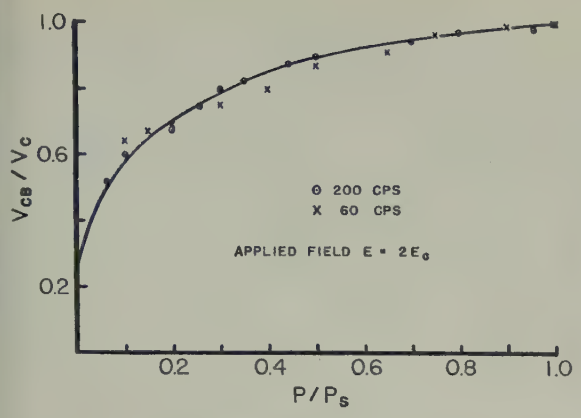

Fig. 7—Variation of coercive voltage as a function of unblocked fraction of P_S.

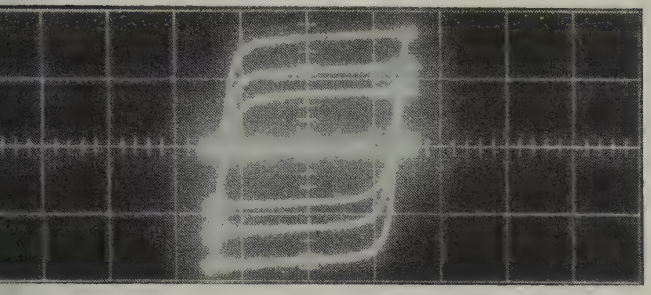

Fig. 8—Hysteresis loops of the transpolarizer for various settings.

ocked or saturated polarization) in function of unocked fractions of P_s. It can be seen that, as blocked larization increases and unblocked polarization deeases, the coercive voltage decreases.

A further important feature of the partially blocked ate is that any level of unblocked polarization can be t. Fig. 8 is a photograph showing a family of hysteresis ops, each pertaining to a different setting including e completely blocked and unblocked maximum setngs, and showing that, when a low polarization level is t, repetition rate can be increased up to a megacycle higher (see Fig. 9). Since any appreciable hysteresis sufficient for a transpolarizer action, it is apparent at very little power is required for control purposes. s an illustration, a transpolarizer using as a dielectric GS or TGFB whose polarization is about 3×10^{-6} oulomb/cm² with an area of $A=5.25\times10^{-6}$ cm² and a ercive voltage of 5 volts needs only about 10^{-10} watt-cond, or less, for setting. If the area $A=25\times10^{-4}$ cm d $BaTiO_3$ is used, this increases to about 3×10^{-7} att-second. Small transpolarizers have been controlled ith electron beams[9] in the microsecond region and it is sualized that new, large-scale storage, display[7] and ck-up, etc., devices would now be practical.

[9] F. Weekes, "The effect of secondary electron emission on the itching transient of ferroelectrics," unpubl. Master's thesis, Dept. ec. Engrg., The Catholic University of America, Washington, D.C.; nuary, 1959.

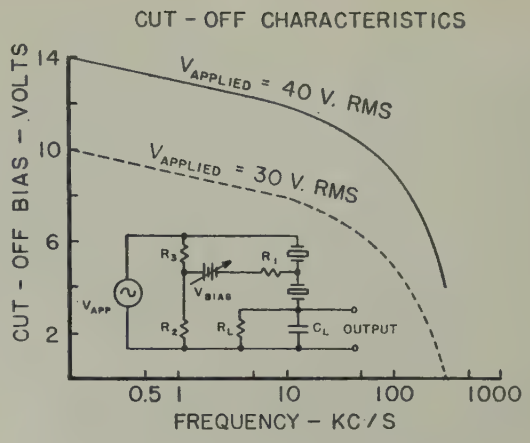

Fig. 9—Cutoff characteristic of a transpolarizer as a function of frequency.

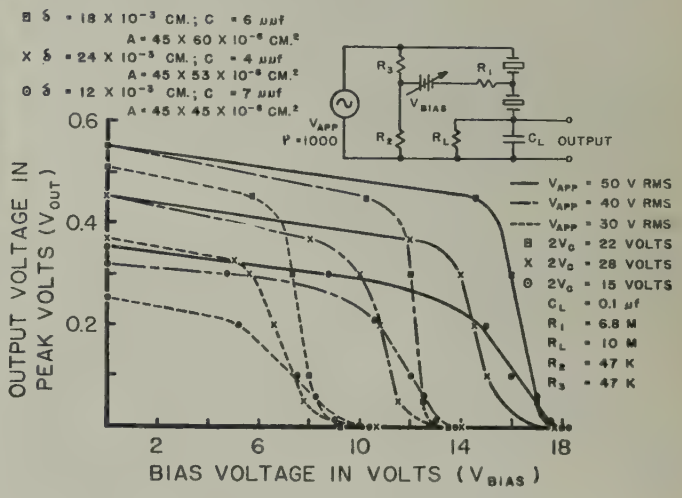

Fig. 10—Cutoff characteristic of a transpolarizer with capacitive load.

Blocking Characteristics

When the blocking characteristic of a two-path transpolarizer is investigated, the control function of an applied bias is of interest. Fig. 10 presents a $BaTiO_3$ transpolarizer with a capacitive load. A low measuring frequency of 1000 cps was applied in this case; this permits observation of a hysteresis loop. R_L was a large value of 10 megohms which served only to secure a path for the bias. The variable bias was applied through $R_1=6.8$ megohms. Its value was so chosen that its shunt effect on the storage elements should be negligible. $R_2=R_3$ was 47 Kohm. P_r could be calculated from the output voltage on the load capacity C_L and area of condenser. The output voltage is given as the half-loop height, which corresponds to a charge transfer through the transpolarizer,

$$Q = P_rA = VC_L. \quad (1)$$

Because the transpolarizer transfers Q with an applied

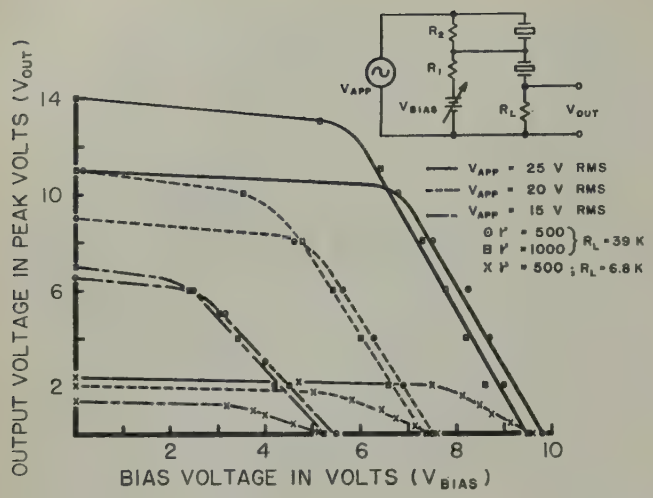

Fig. 11—Cutoff characteristic of a transpolarizer with resistance load.

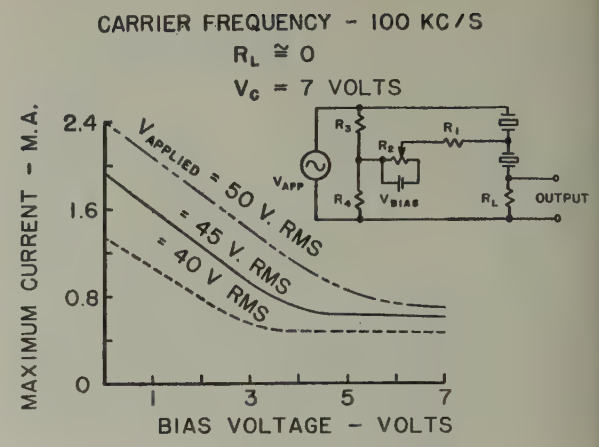

Fig. 12—Short-circuited transfer characteristic at 100 kc/s as a function of bias voltage and applied voltage.

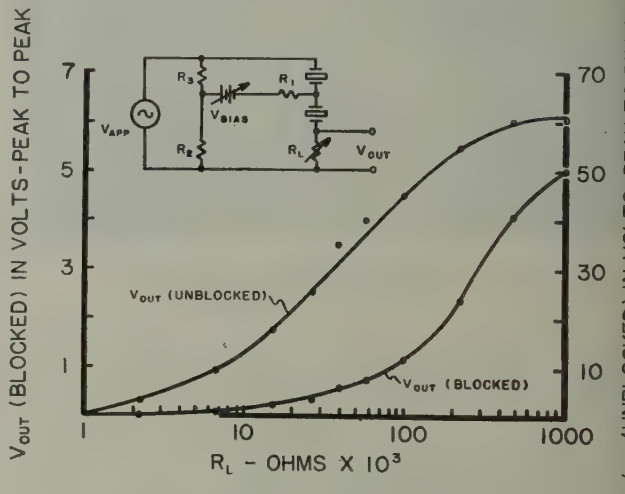

Fig. 13—Signal-to-noise ratio as a function of load resistance.

voltage of V_{app}, the nonlinear capacitance C_T, during switching of the unblocked polarization becomes,

$$C_T = \frac{Q}{(V_{app} - V_{out})} . \qquad (2)$$

Using the data given in Fig. 10, the maximum value of C_T was approximately 1000 $\mu\mu$f and the minimum value of C_T when blocked was approximately 3–4 $\mu\mu$f for the two condensers in series. This gives an impedance ratio of approximately 300:1, which agrees well with data obtained by resonance measurements. A similar measurement was made when TGS and TGFB were used as dielectrics; the impedance ratio for these cases was found to be about 1000:1.

Fig. 10 gives variation of output voltage as the dc bias was varied. It is apparent from this measurement that a rather sharp threshold or cutoff bias value exists which depends only slightly on crystal thickness, and mainly on applied voltage. As energizing voltage increases, blocking potential required as a bias also increases. These characteristic plots present the blocking function of the bias.

Fig. 11 gives a similar plot with a resistive load. In this case the output was not sinusoidal and i_{max} was measured, and since no integration occurs, the blocking potential gave a sharper threshold value. The application of dc bias was slightly different. In this case, the frequency of applied voltage, as well as load resistance, was varied to see what effect this would have on the cutoff bias. For the frequency used, R_L is negligible compared to the capacitive reactances and would not have much effect on total current. Therefore, cutoff will not be affected significantly by R_L but the output voltage will be proportional to R_L. This circuit can be used as a power amplifier, chopper, etc. Using the same basic circuit as shown in Fig. 10, the variation of cutoff bias was measured when the frequency of applied energizing voltage was varied. In Fig. 9, the cutoff values are given for V_{app}=30 and 40 v. This measurement indicates that, when the frequency of V_{app} increases, a lower cutoff bias is required to set the blocked state. This plot also shows that, in a partially blocked state, repetition rate can be increased up to the megacycle region.

Fig. 12 gives the short-circuited transfer characteristic (because R_L was nearly 0) at 100 kc in function of bias voltage and applied field. Regarding the transpolarizer as a four-terminal network, the maximum power gain attainable was 2100. The input impedance of the device was 30 megohms while the output impedance was found to be 1 Kohm, at this power gain. A TGS transpolarizer was used for these measurements.

Although this paper discusses the two-section transpolarizer with two elements of nearly equal electrical and physical characteristics, the foregoing applies also to a multisection transpolarizer composed of asymmetrical elements.

For the measurements presented in Fig. 9 and Figs. 11–13, $BaTiO_3$ transpolarizers were used having a coercive voltage V_c=7 volts, an area $A = 45 \times 45 \times 10^{-6}$ cm and a thickness, $\delta = 12 \times 10^{-3}$ cm.

Control Ratio

The device signal-to-noise ratio can be defined as the nal ratio of the unblocked and blocked transpolarizer. g. 13 gives output voltages for the unblocked- and ocked-state when the load resistance R_L is varied and e frequency of applied voltage was constant at 1000 s. As load resistances decrease, signal-to-noise ratios crease and its maximum value is about 100; as the ad resistance increases, this value drops to about 12. though the impedance ratio of a transpolarizer is uch higher (300:1), circuit capacitances increase the nall blocked capacity and this, in turn, decreases the tual obtainable signal-to-noise ratio.

A similar investigation can be carried out when the equency of applied voltage is varied. These measure-ents were not made because special instrumentation ould have been needed to avoid the heating effect in-olved at the higher frequencies.[10] Briefly, it is noted at calculation shows a similar change for increasing equency, *i.e.*, the signal-to-noise ratio decreases with creasing frequency.

Conclusion

The important basic features of the transpolarizer e summarized as follows:

a) Polarization conditions, once set in the two cells, stay permanently and represent a stored control; the transpolarizer, in an "on-off" operating mode, is a basic one-bit storage element whose state can be sensed a large number of times without causing an alteration in its state; consequently, it affords a "nondestructive" read-out.

b) Besides being an "on-off" device, an intermediate setting is possible by using a single appropriate amplitude block- or unblock-pulse according to which an output of any desired level in a continuous range between the blocked- (almost zero) and unblocked-levels can be produced (Fig. 8). This property permits use of only a fraction of the polarization to be switched and a high repetition rate becomes possible.

c) It has also the ability to control a long flow of alternating electric power according to the setting established by a single electric pulse. The energizing ac sensing signal will or will not produce an ac output depending on the sign and amplitude of the last setting, block- or unblock-pulse, respectively.

d) It is a high-impedance input device and a low-impedance output device and needs very little control power; therefore, it is readily controlled by such high-impedance means as an electron beam or photoelectric device.

e) The transpolarizer combines in effect the function of a dielectric amplifier and a ferroelectric storage cell.

The very special switching and storage properties, as well as the stability, of the transpolarizer open a large field of new applications and permit production of new devices and systems employing switching with a permanent setting, and, more particularly, permit production of small- and large-scale storage devices with nondestructive readout, large screen display devices with storage properties, high impedance input switches, and in general, photoelectric switches, decoders, function generators, etc.

The transpolarizer is in effect a solid state relay, *i.e.*, a switching device with storage ability and simple construction. It is rugged and stable in operation; no permanent deterioration can occur by overdriving any of the associated circuits.

Acknowledgment

The author wishes to acknowledge the assistance of George E. McDuffie, Jr., Wolf Kuebler, and E. Joseph Thompson who helped in many experimental phases of the work and greatly contributed to the functional understanding of the transpolarizer.

[10] J. Hou-Ying Tai, "Pulsed sine-wave hysteresis loop of $BaTiO_3$," npubl. Master's thesis, Dept. Elec. Engrg., The Catholic University America, Washington, D. C.; May, 1957.

Geometric-Analytic Theory of Transition in Electrical Engineering*

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Summary—A geometric-analytic theory of transition is presented and applied to circuit theory. A transition from one state to another is represented in a complex plane by two points which, by variation of a parameter, approach each other, coalesce, and then separate along trajectories perpendicular to the original trajectories.

Three analogous cases are treated, namely

1) Movements of fixed points in the complex impedance plane and the complex reflection coefficient plane (Smith chart),
2) Movements of poles in the complex frequency plane, and
3) Movements of saddle points in the complex frequency plane.

In the analytic treatment, the linear fractional transformation (Moebius transformation) is used, which makes conformal graphical methods applicable in the geometric treatment. Such a method is, for example, the isometric circle method.

By mapping stereographically the complex plane on the Riemann unit sphere, we see that a transition can be represented in three dimensions by the movements of two straight lines, each being the polar of the other with respect to the sphere. The transition takes place when both lines are perpendicular and tangent to the sphere at a point corresponding to the transition point.

I. Introduction

A COMPLEX quantity $w=u+jv(j^2=-1)$ can be represented by a point with the coordinates u and v in a plane. The use of such a "complex plane" seems to have been suggested independently by Wessel (1745–1818), Argand (1768–1822), and Gauss (1777–1855). Ever since Steinmetz, in 1895, introduced the complex plane in electrical engineering, this simple mathematical tool has obtained extensive applications, especially in circuit theory.

In the present paper, the complex plane will be used in a simple geometric-analytic theory of transition in electrical engineering. The geometric part of the theory utilizes two "isometric" circles which are usually used in connection with a graphical method of transforming a complex quantity by means of the linear fractional transformation (Moebius transformation), called the "isometric circle method."[1] The analytic part consists of the use of quadratic equations. After a brief study of these tools, we are going to investigate some simple examples of fixed point trajectories in the complex impedance and reflection coefficient planes, and pole and saddlepoint trajectories in the complex frequency plane.

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[1] E. F. Bolinder, "Impedance and polarization-ratio transformations by a graphical method using the isometric circles," IRE TRANS. ON MICROWAVE THEORY AND TECHNIQUES, vol. MTT-4, pp. 176–180; July, 1956.

II. Isometric Circles

The isometric circle is defined as the circle that is the complete locus of points in the neighborhood of which lengths are unaltered in magnitude by the linear fractional transformation

$$w' = \frac{aw + b}{cw + d}, \qquad ad - bc = 1 \tag{1}$$

where $w=u+jv$, $w'=u'+jv'$, and a, b, c, and d are complex constants obeying the condition $ad-bc=1$.

From (1) we obtain

$$\frac{dw'}{dw} = \frac{1}{(cw + d)^2}, \qquad ad - bc = 1, \tag{2}$$

so that the isometric circle of the direct transformation is

$$|cw + d| = 1, \qquad c \neq 0. \tag{3}$$

Similarly, the inverse transformation

$$w = \frac{-dw' + b}{cw' - a}, \qquad ad - bc = 1 \tag{4}$$

has the isometric circle

$$|cw' - a| = 1, \qquad c \neq 0. \tag{5}$$

Thus the isometric circle of the first direct transformation, C_d, has its center at $O_d=-d/c$ and radius $R_c=1/|c|$; the isometric circle of the inverse transformation, C_i, has its center at $O_i=a/c$ and the same radius. See Fig. 1.

Mathematically, (1) is divided into two classes of transformation: the loxodromic transformation, characterized by $a+d=$complex, and the nonloxodromic transformation, characterized by $a+d=$real. The second class is further divided into hyperbolic ($|a+d|>2$), parabolic ($a+d=\pm 2$), and elliptic ($|a+d|<2$) transformations.

In Fig. 1 the isometric circle method is outlined. It consists in the loxodromic case of 1) an inversion in the isometric circle of direct transformation C_d, $(w\rightarrow w_1)$; 2) a reflection in the symmetry line L to the two circles, $(w_1\rightarrow w_2)$; and 3) a rotation around the center O_i of the isometric circle of the inverse transformation through an angle -2 arg $(a+d)$, $(w_2\rightarrow w')$. In the nonloxodromic case $a+d=$real, so that the third operation is eliminated $(w_2=w')$. In this work only the isometric circles and not the isometric circle method itself will be used.

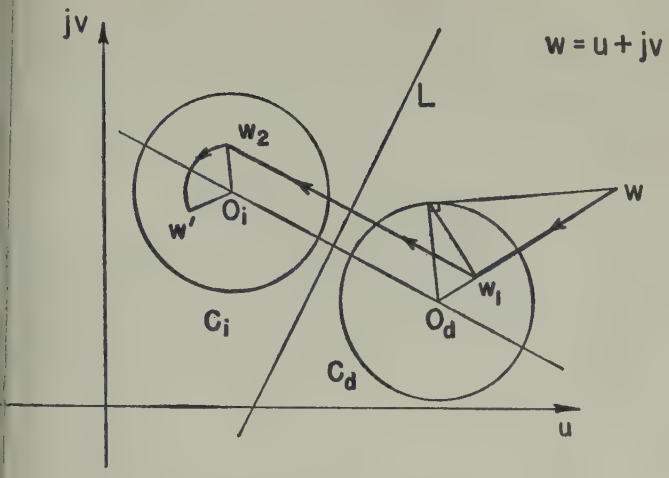


Fig. 1—The isometric circle method.

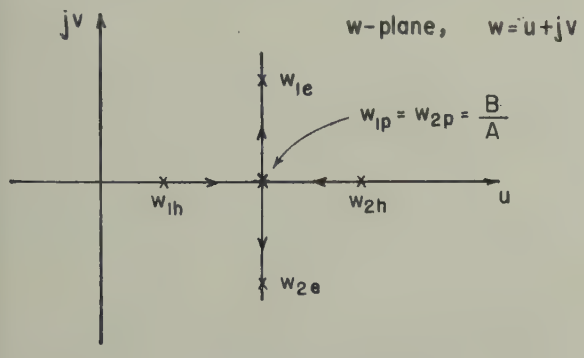


Fig. 2—The roots of a quadratic equation plotted in a complex plane.

III. Quadratic Equations

If we solve an arbitrary complex quadratic equation

$$Aw^2 - 2Bw + C = 0 \tag{6}$$

where A, B, and C are real constants, we obtain

$$\left.\begin{matrix} w_1 \\ w_2 \end{matrix}\right\} = \frac{B}{A} \pm \frac{\sqrt{B^2 - AC}}{A}. \tag{7}$$

In (7) B^2-AC is called the discriminant. If the discriminant is positive, two real roots w_{1h} and w_{2h} are obtained which we can plot in the complex w plane. See Fig. 2. If the discriminant is negative, two conjugate complex roots w_{1e} and w_{2e} are obtained:

$$\left.\begin{matrix} w_{1e} \\ w_{2e} \end{matrix}\right\} = \frac{B}{A} \pm j\frac{\sqrt{AC - B^2}}{A}. \tag{8}$$

See Fig. 2. Finally, if the discriminant equals zero the two roots coalesce and we obtain

$$w_{1p} = w_{2p} = \frac{B}{A}. \tag{9}$$

If we assume that the constants A, B, and C are functions of a certain parameter, then, by varying the parameter, w_1 and w_2 may approach each other, coalesce, and separate along trajectories perpendicular to the original trajectories. A "transition" between two "states" is obtained. We are now going to study simple examples of how such a transition may occur in connection with fixed point trajectories in the impedance and reflection coefficient planes, and pole and saddle-point trajectories in the complex frequency plane.

IV. Fixed Point Trajectories

Impedance and Reflection Coefficient Transformations Through Bilateral Two-Port Networks

The input voltage V' and the input current I' of a bilateral two-port network can be expressed in the output voltage V and output current I by the following linear equations:

$$\left.\begin{aligned} V' &= aV + bI \\ I' &= cV + dI \end{aligned}\right\} \tag{10}$$

where, at a fixed frequency, the four complex constants satisfy the reciprocity relations

$$ad - bc = 1. \tag{11}$$

If we put

$$\left.\begin{aligned} \frac{V'}{I'} &= Z' \\ \frac{V}{I} &= Z \end{aligned}\right\}, \tag{12}$$

we obtain

$$Z' = \frac{aZ + b}{cZ + d}; \qquad ad - bc = 1. \tag{13}$$

This is a linear fractional transformation. By using the property that the imaginary axis of the Z-plane, $Z=R+jX$, is invariant under a lossless transformation, we obtain for such a transformation

$$Z' = \frac{a'Z + jb''}{jc''Z + d'}, \qquad a'd' + b''c'' = 1 \tag{14}$$

where

$$\left.\begin{aligned} a &= a' + ja'' \\ b &= b' + jb'' \\ c &= c' + jc'' \\ d &= d' + jd'' \end{aligned}\right\}. \tag{15}$$

The fixed points of (14) are:

$$\left.\begin{matrix} Z_{f1} \\ Z_{f2} \end{matrix}\right\} = \frac{a' - d' \pm \sqrt{(a' + d')^2 - 4}}{2jc''}. \tag{16}$$

By using (14) and the well known expression for the reflection coefficient

$$\Gamma = \frac{\dfrac{Z}{\sqrt{2}} - \dfrac{1}{\sqrt{2}}}{\dfrac{Z}{\sqrt{2}} + \dfrac{1}{\sqrt{2}}}; \qquad \Gamma' = \frac{\dfrac{Z'}{\sqrt{2}} - \dfrac{1}{\sqrt{2}}}{\dfrac{Z'}{\sqrt{2}} + \dfrac{1}{\sqrt{2}}}, \tag{17}$$

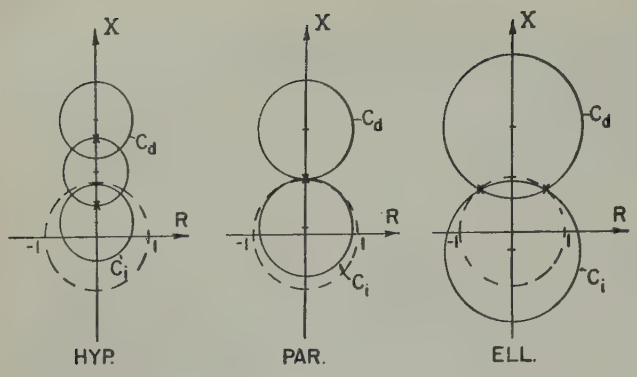


Fig. 3—Fixed point trajectories in the complex impedance plane.

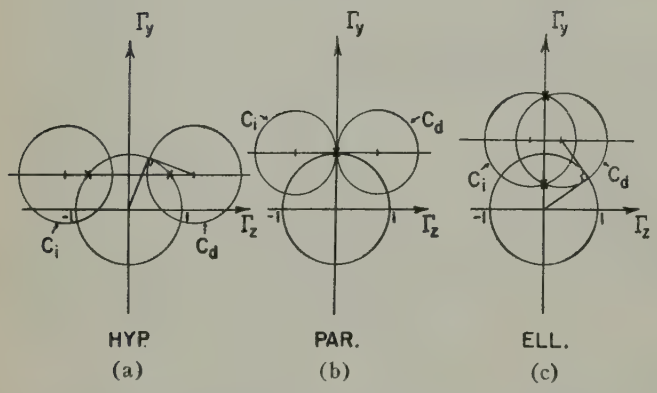


Fig. 4—Fixed point trajectories in the complex reflection coefficient-plane (Smith chart).

we obtain

$$\Gamma' = \frac{A\Gamma + C^*}{C\Gamma + A^*} \tag{18}$$

where an asterisk indicates a conjugate complex quantity, and

$$\left.\begin{aligned} A &= \tfrac{1}{2}[(a' + d') - j(b'' + c'')] \\ C &= \tfrac{1}{2}[(a' - d') - j(b'' - c'')] \end{aligned}\right\}. \tag{19}$$

Fixed Point Trajectories in the Z Plane and the Smith Chart, and on the Riemann Sphere

Since the distance between the centers of the two isometric circles in the nonloxodromic case is $(a'+d')/c''$, while the sum of the two radii is $2/c''$, it follows that the hyperbolic case is obtained, if the two circles are external; the parabolic case, if they are tangent; and the elliptic case, if they intersect. In the Z plane the isometric circles have their centers on the imaginary axis in the lossless case. A simple example indicating the isometric circle positions of a lossless exponentially tapered transmission line is shown in Fig. 3. A geometric interpretation of (16) shows that in the hyperbolic or below cutoff case, the fixed points are obtained where a circle, orthogonal to the two isometric circles, cuts the imaginary axis. In the parabolic or cutoff case,

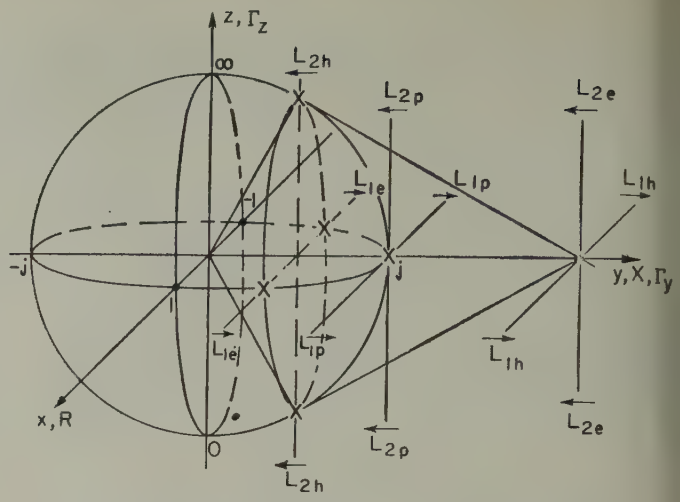


Fig. 5—Fixed point trajectories of the Riemann unit sphere.

the fixed points coalesce at the point of tangency of the two isometric circles. Finally, in the elliptic or above cutoff case, the fixed points constitute the crossover points of the two isometric circles. We find, that if we vary a parameter, for example, the length of the line or the frequency, the fixed points move on the imaginary axis, coalesce, and then separate perpendicularly to the original trajectories following the unit circle.

The corresponding trajectories in the Smith chart are shown in Fig. 4. Here the fixed points move on the unit circle in the hyperbolic case, coalesce, and then separate perpendicularly following the imaginary axis of the Γ-plane ($\Gamma = \Gamma_z + j\Gamma_y$) in the elliptic case.

If we map the Z plane stereographically on the unit Riemann sphere with the top of the sphere, $(x, y, z) = (0, 0, 1)$, as projection center, the Smith chart is obtained in the yz plane by an additional stereographic projection from the point $(-1, 0, 0)$.[2-4] See Fig. 5. By plotting the fixed point trajectories of the lossless exponentially tapered transmission line studied above on the sphere, we find that by using three dimensions the discontinuous movements of the fixed points in two dimensions are replaced by a continuous movement. In the elliptic case, the fixed points move on the unit circle in the xy plane. We connect the points by a straight line L_{1e} parallel to the x axis. This line has a polar line L_{2e} parallel to the z axis. When the line L_{1e} moves towards the point $(0, 1, 0)$, L_{2e} moves towards the same point. In the parabolic case both lines, now called L_{1p} and L_{2p}, are tangent to the sphere. If the lines continue their movements the hyperbolic case is obtained. Now the

[2] F. Steiner, "Die Anwendung der Riemannschen Zahlenkugel und ihrer Projektionen in der Wechselstromtechnik," *Radiowelt*, vol. 1, pp. 23–26; October, 1946.

[3] H. A. Wheeler, "Geometric relations in circle diagrams of transmission-line impedance," *Wheeler Monographs*, Wheeler Labs., Great Neck, N. Y., vol. 1, no. 4; 1948.

[4] G. A. Deschamps, "Geometric viewpoints in the representation of waveguides and waveguide junctions," *Proc. Symp. on Modern Network Synthesis*, Polytechnic Inst. of Brooklyn, Bklyn., N. Y., vol. 1, pp. 277–295; April, 1952.

rst line, called L_{1h}, falls outside the sphere, while the econd line L_{2h} cuts the sphere in the fixed points situted on the unit circle in the yz plane. Thus a smooth ransition between the elliptic and hyperbolic states is btained.

V. Pole Trajectories

The Resonant Circuit

The input impedance of a simple parallel resonance ircuit consisting of an inductance L with a series reistance r, and a capacitance C with a conductance G see Fig. 6) is

$$Z(s) = \frac{1}{C}\,\frac{s + r/L}{s^2 + (r/L + G/C)s + (1 + rG)/LC} \tag{20}$$

where s is the complex frequency, $s=\sigma+j\omega$. Eq. (20) can be written

$$Z(s) = \frac{1}{C}\,\frac{1}{s + \dfrac{sG/C + (1 + rG)/LC}{s + r/L}}\,. \tag{21}$$

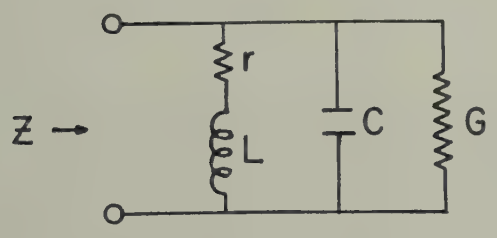


Fig. 6—Resonant circuit.

The positions of the poles, s_{p1} and s_{p2}, are obtained by making the denominator equal to zero

$$s_p = \frac{-s_pG/C - (1 + rG)/LC}{s_p + r/L}\,. \tag{22}$$

Eq. (22) is analogous to the equation used in the preceding section in obtaining the fixed points Z_{f1} and Z_{f2} of the linear fractional transformation (13). To obtain an exact analogy, the coefficients in (22) have to obey the condition $ad-bc=1$. Eq. (22) then transforms into

$$s_p = \frac{-s_pG\sqrt{L/C} - (1 + rG)/\sqrt{LC}}{s_p\sqrt{LC} + r\sqrt{C/L}}\,. \tag{23}$$

Pole Trajectories in the Complex Frequency Plane and on the Riemann Sphere

In the Z plane, the positions of the fixed points were obtained from the positions of the isometric circles. Analogous conditions yield two circles in the s plane with centers at $-d/c=-r/L$ and $a/c=-G/C$, both having the radius $1/|c|=1/\sqrt{LC}=\omega_0$, the resonance (radian) frequency. The positions of these circles immediately specify the pole positions. See Fig. 7. If the

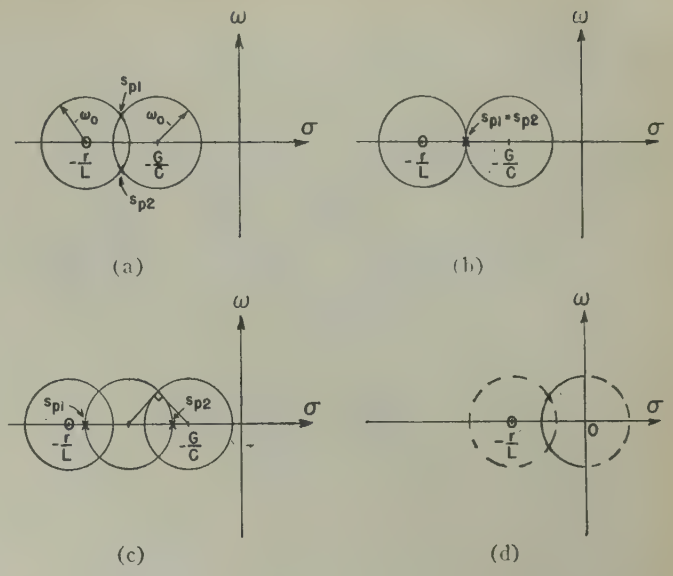


Fig. 7—Pole trajectories in the complex frequency plane.

two circles intersect [Fig. 7(a)], two complex conjugate poles are obtained, corresponding to the damped oscillatory case. If the two circles are tangent [Fig. 7(b)], two coalescing real poles are obtained, corresponding to the critically damped case. If, finally, the two circles are external [Fig. 7(c)], two real poles are obtained as the crossover points of the real axis and a circle that is orthogonal to the two given circles, corresponding to the aperiodic case. In all cases one zero of (20) is situated at infinity, $s_{01}=\infty$, and another at $s_{02}=-r/L$.

Thus, we find that by varying the conductance G, for example, the poles follow the fixed circle with its center at $-r/L$, coalesce, and then separate perpendicularly following the real axis. In various textbooks, we find that the pole trajectories shown in Fig. 7(d) are obtained for an rLC circuit by varying the resistance r. This figure is immediately explained by the graphical method that has been described. With $G=0$, one circle is fixed with its center at the origin of the s plane, and the other moves along the negative real axis as r is varied. The trajectories are therefore the real axis and the fixed circle.

If we map the s plane stereographically on the unit Riemann sphere, the example chosen can be treated by the polar theory of the preceding section. See Fig. 8. The pole trajectories on the sphere are indicated by heavy lines.

VI. Saddlepoint Trajectories

The Inverse Laplace Transform Treated by the Saddlepoint Method

Saddlepoints of the second order play an important role in methods of approximate integration of the inverse Laplace transform

$$f(t) = \frac{1}{2\pi j}\int_{\gamma_s} F(s)e^{st}ds; \qquad s = \sigma + j\omega. \tag{24}$$

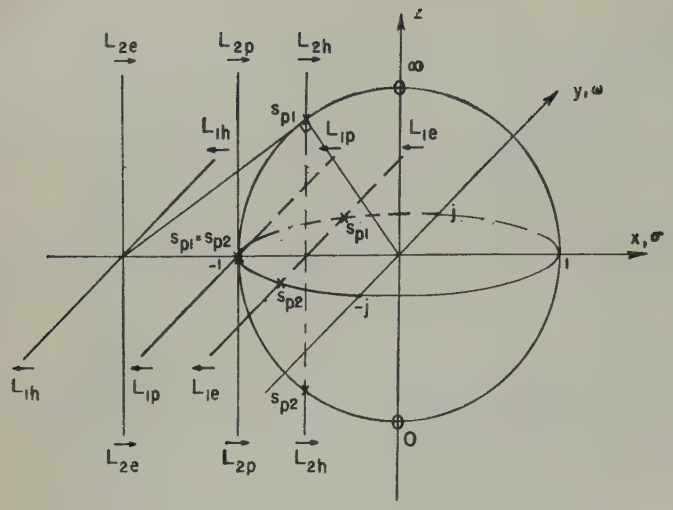


Fig. 8—Pole trajectories on the Riemann unit sphere.

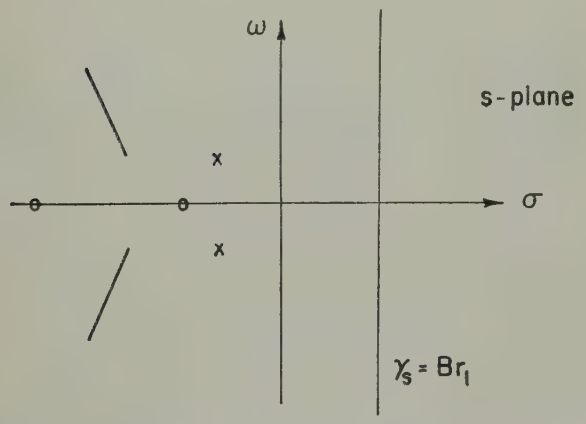


Fig. 9—Example of poles, zeros, branch-cuts, and the Bromwich-1 contour of integration in the complex frequency plane.

In (24), t indicates time, and γ_s the contour of integration in the s plane. This contour of integration may be a straight line parallel to the ω axis ("Bromwich—1" contour) (see Fig. 9) or the topologically equivalent contour folded around the singularities in the left half of the s plane ("Bromwich—2" contour).

We can write (24) in the following form:

$$f(t) = \frac{1}{2\pi j}\int_{\gamma_s} e^{\ln F(s)+st}ds = \frac{1}{2\pi j}\int_{\gamma_s} e^{W(s,t)}ds. \quad (25)$$

If we put

$$\frac{\partial W(s,t)}{\partial s} = 0, \quad (26)$$

the roots of (26) correspond to points, called saddlepoints, in the s plane. These points, which are used in a theory of approximate integration—"the saddlepoint method" (first invented by B. Riemann in 1863)—follow certain trajectories in the s plane when the time t varies. The contour of integration is changed until it passes through the saddlepoints along the paths of

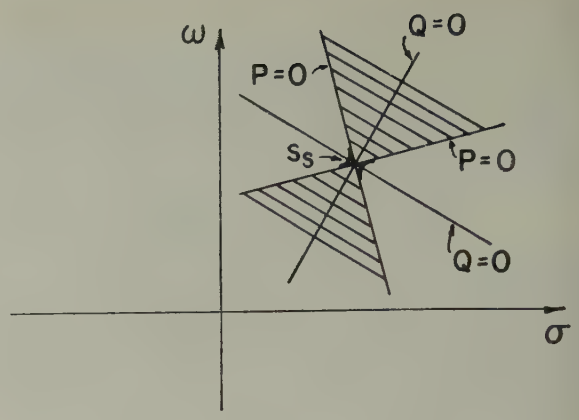
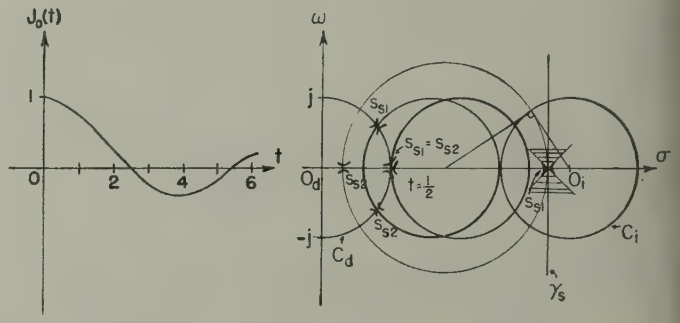


Fig. 10—$P=0$ and $Q=0$ lines through a saddlepoint of second order.



(a) (b)

Fig. 11—(a) The Bessel function of the first kind and of order zero. (b) Saddlepoint trajectories in the complex frequency plane.

steepest descent. These paths are found by expanding $W(s, t)$ in a Taylor series in the vicinity of the saddlepoint s_s.[5] We put

$$W(s, t) - W(s_s, t) = P + jQ \quad (27)$$

and determine the line $Q=0$ for which the real part of $W(s, t) - W(s_s, t)$ is maximum negative. In Fig. 10 the region of $P<0$ around a saddlepoint of the second order is shadowed. The line $Q=0$ in that region constitutes the line of steepest descent.

Let us study a simple example.[5] The Bessel function of the first kind and of order zero, $J_0(t)$, plotted in Fig. 11(a), has the Laplace transform $1/\sqrt{s^2+1}$, so that

$$f(t) = J_0(t) = \frac{1}{2\pi j}\int_{\gamma_s} \frac{1}{\sqrt{s^2+1}}\, e^{st}ds. \quad (28)$$

Here

$$\frac{\partial W(s,t)}{\partial s} = -\frac{s}{s^2+1} + t = 0 \quad (29)$$

[5] M. V. Cerrillo, "On the evaluation of integrals of the type

$$f(\tau_1, \tau_2, \cdots \tau_n) = \frac{1}{2\pi j}\int F(s)e^{W(s,\tau_1,\tau_2,\cdots\tau_n)}ds$$

and the mechanism of formation of transient phenomena," in "An Elementary Introduction to the Theory of the Saddlepoint Method of Integration," Res. Lab. of Electronics, M.I.T., Cambridge, Mass., Tech. Rep. No. 55:2a; May 3, 1950.

ields

$$s_s = \frac{(s_s/t) - 1}{s_s} \tag{30}$$

r

$$\left.\begin{matrix} s_{s1} \\ s_{s2} \end{matrix}\right\} = \frac{1}{2t} \pm \sqrt{\left(\frac{1}{2t}\right)^2 - 1}. \tag{31}$$

Eq. (30) is analogous to the equation used in Section V in obtaining the fixed points Z_{f1} and Z_{f2} of the linear fractional transformation (13).

Saddlepoint Trajectories in the Complex Frequency Plane and on the Riemann Sphere

In the Z plane, the positions of the fixed points were obtained from the positions of the isometric circles. Analogous conditions yield, for our chosen saddlepoint example, two circles in the s plane with centers at $-d/c=0$ and $a/c=1/t$, both having the radius $1/|c|=1$. The positions of these circles immediately specify the saddlepoint positions. See Fig. 11(b). For $t=0$; one saddlepoint is situated at the origin of the s plane and another at infinity. For small t, when the two circles are external, the saddlepoint positions are obtained as the crossover points between the circle orthogonal to the two circles and the real s axis. At $t=\frac{1}{2}$, the two original circles are tangent and the two saddlepoints coalesce at $s=(1, 0)$, thereby creating a saddlepoint of the third order.[5] When $t>\frac{1}{2}$ the two circles intersect and the saddlepoints separate perpendicularly to the σ axis following the unit circle in the s plane. Finally, when $t\to\infty$, the saddlepoints approach the points $s=(0, \pm j)$.

It is interesting to note that the velocities with which the saddlepoints travel along the σ axis increase as the points approach the transition point $s=(1, 0)$ and become infinite at that point. The velocities with which they separate are again infinite. If, however, we map the complex frequency plane stereographically on the Riemann unit sphere and introduce the polar theory of Sections IV and V, we find that the polars pass with finite velocities through the transition point $(x, y, z)=(1, 0, 0)$.

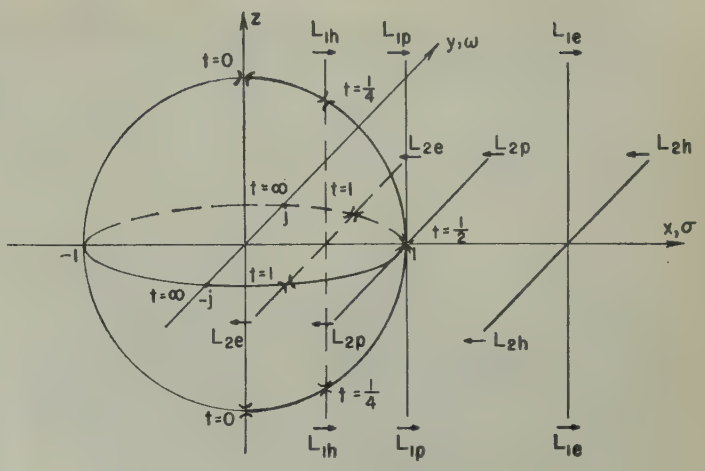


Fig. 12—Saddlepoint trajectories on the Riemann unit sphere.

The fact that the saddlepoints move approximately in the tangent plane at that point, accounts for the great velocities of the saddlepoints near to $s=(1, 0)$ in the s plane. In Fig. 12, the saddlepoint trajectories on the Riemann sphere are indicated by heavy lines.

VII. Conclusion

In the geometric-analytic theory of transition presented, we have used the complex plane and the Riemann sphere in the geometric treatment, and the theory of quadratic equations in the analytic treatment. By selecting simple examples, similar trajectories were obtained for two fixed points, poles, or saddlepoints in the complex plane and on the sphere. All points were obtained by equating a quadratic to zero. Transitions between two states were studied by using the complex plane and the Riemann sphere, the latter considered to be imbedded in a three-dimensional space.

The geometric-analytic theory constitutes an integral part of a more general transition theory in physics. The main purpose of the theory presented is to provide a stimulus for continued research on the use of modern geometry in electrical engineering.

A Phenomenological Theory of the Reggia-Spencer Phase Shifter*

JERALD A. WEISS†

Summary—The novel ferrite-actuated variable phase shifter reported by F. Reggia and E. G. Spencer operates on a principle which, while resembling that of the familiar Faraday rotation devices, differs from them in a way which leads to quite different and unexpected behavior. The observed properties of the device depend on the interaction between the radiation and the ferrite taking place under several special conditions: namely, elliptic waveguide symmetry, a variation in the permeability associated with the magnetic disorder of the unsaturated ferrite, and a dielectric-waveguide effect.

The essential properties of the device can be explained with the aid of a simplified model in which the radiation is represented by plane waves. The contribution of the dielectric-waveguide effect can be estimated on the basis of known solutions of a simpler problem, namely that of a dielectric rod partially filling circular guide.

The model furnishes insight into the characters of the modes of propagation under conditions resembling those of the Faraday rotator but subject to elliptic symmetry and other complications.

Introduction

A VARIABLE microwave phase shifter, employing a longitudinally magnetized ferrite rod in rectangular waveguide has been described by Reggia and Spencer.[1] The structure has also been mentioned by Brown, Cole, and Honeyman.[2] The behavior of the device differs radically from that of the well-known Faraday rotator which it resembles, suggesting that the two effects are special cases of a more general principle, or combination of principles, which may lead to a variety of novel devices. The phase shifter itself offers a fresh approach to the problem of producing phase variations under conditions appropriate to the various applications, such as scanning antennas, bridge circuits, etc.

The following discussion presents a composite phenomenological model which exhibits the essential properties of the Reggia-Spencer phase shifter and incorporates the minimum number of contributing phenomena required to produce the over-all effect. The aim of the model is to reduce the problem to such a degree of simplicity that it can be solved without recourse to numerical methods, thereby providing an advantageous starting point for such calculations, as well as a qualitative guide to further experimental development.

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[1] F. Reggia and E. G. Spencer, "A new technique in ferrite phase shifting for beam scanning of microwave antennas," PROC. IRE, vol. 45, pp. 1510–1517; November, 1957.

[2] A. C. Brown, R. S. Cole, and W. N. Honeyman, "Some applications of ferrites to microwave switches, phasers, and isolators," PROC. IRE, vol. 46, pp. 722–727; April, 1958.

Structure and Behavior of the Phase Shifter

The device consists simply of a ferrite rod mounted on the axis of a section of standard rectangular waveguide and magnetized longitudinally by means of a solenoid. See Fig. 1. Large variations in the phase of the transmitted radiation occur in the range of applied magnetic fields in which the ferrite is partially magnetized. The effect is reciprocal: on application of the dc field, the change in phase shift (usually increasing at first) is the same for both directions of propagation. Typical data are shown by Reggia and Spencer[1] and in Figs. 2 and 3. After reaching a maximum at a field corresponding approximately to the saturation magnetization of the ferrite, the phase decreases slowly with further increase in the field. Associated with the phase variation is an undulation in insertion loss which is, however, too small to be accounted for by rotation effects. It can be minimized by means of familiar matching techniques such as those employed by Reggia and Spencer;[1] namely, tapering of the ferrite rod or addition of dielectric matching elements. Variations in insertion loss between a minimum of 0.5 db and a maximum of 1.5 db are typical when no special provision is made for matching. The amount of phase shift is approximately proportional to the length of the rod and is frequency sensitive to a degree; see Fig. 3. It is extremely sensitive to the diameter of the rod, undergoing a spectacular increase over a narrow range whose significance will be discussed below. Finally, it is roughly proportional to the saturation magnetization of the ferrite.

The Phenomena Contributing to the Behavior of the Phase Shifter

A theoretical representation of this device is required to show at least the following details: 1) The origin of the large phase shift; 2) Why large fluctuations in transmission with changes in frequency and applied field, such as would be associated with Faraday rotation,[3,4] do not occur; 3) What parameters determine the operating range of the device; 4) What role is played by the magnetic and dielectric properties of the ferrite; 5) Some

[3] C. L. Hogan, "The ferromagnetic Faraday effect at microwave frequencies and its applications," *Rev. Mod. Phys.*, vol. 25, pp. 253–263; January, 1953.

[4] J. A. Weiss, "An interference effect associated with Faraday rotation, and its application to microwave switching," *Proc. AIEE Conf. on Magnetism and Magnetic Materials*, Boston, Mass., pp. 580–585; October, 1956.

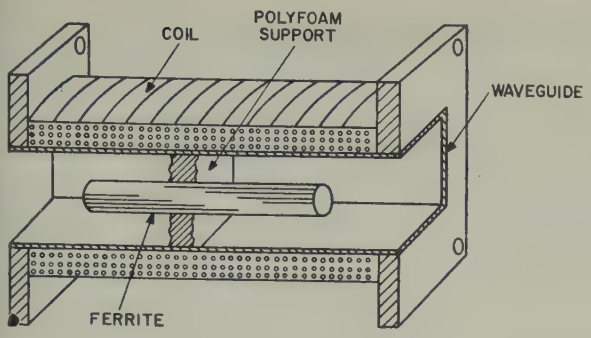

Fig. 1—Cutaway view of a Reggia-Spencer phase shifter.

eneral features of the modes of propagation; 6) What onsiderations govern the scattering characteristics of he ferrite-loaded section.

The development presented below provides more or ess schematic information on these points. It will be hown there that the phase shift arises essentially from variations in the diagonal component μ of the permeability tensor[5] which characterizes the ferrite, the off-diagonal component κ playing a secondary role. As shown in Fig. 5, the quantity μ starts from a value somewhat less than one in the unmagnetized ferrite and increases abruptly on application of the longitudinal dc field, nearly reaching one as the material saturates and then decreasing again. This phenomenon originates in the presence of internal demagnetizing fields[6] associated with the magnetic disorder of the partially magnetized polycrystalline ferrite. The increase in μ causes a redistribution of the radiation fields with the wave concentrating progressively more heavily in the rod; that is, the tendency of the rod to behave as a dielectric waveguide is steadily enhanced. Associated with this redistribution is a decrease in guide wavelength which results in the observed phase variations.

Although the high dielectric constant of the ferrite (typically about ten times that of air) plays an important part in the effect, the immediate cause of the *variations* in phase is magnetic in origin. Thus the phenomenon might properly be called a "variable-dielectric-magnetic-waveguide effect." Since the field configurations involved are, however, of the same general character as those encountered in the familiar case of a purely dielectric rod, we shall for brevity use the term "dielectric waveguide."

In a range of rod diameters in which this variable-

[5] D. Polder, "On the theory of ferromagnetic resonance," *Phil. Mag.*, vol. 40, pp. 99–115; January, 1949. The components μ and κ of the permeability tensor are given in terms of the magnetization M, dc magnetic field H, angular frequency ω, and the gyromagnetic ratio $\gamma \cong 2.8$ mc per oersted, as

$$\mu = 1 + \frac{4\pi\gamma^2 MH}{\gamma^2 H^2 - \omega^2}, \qquad \kappa = \frac{4\pi\gamma M\omega}{\gamma^2 H^2 - \omega^2}.$$

[6] See R. C. LeCraw and E. G. Spencer, "Domain structure effects in an anomalous ferrimagnetic resonance of ferrites," *J. Appl. Phys.*, vol. 28, pp. 399–405; April, 1957.

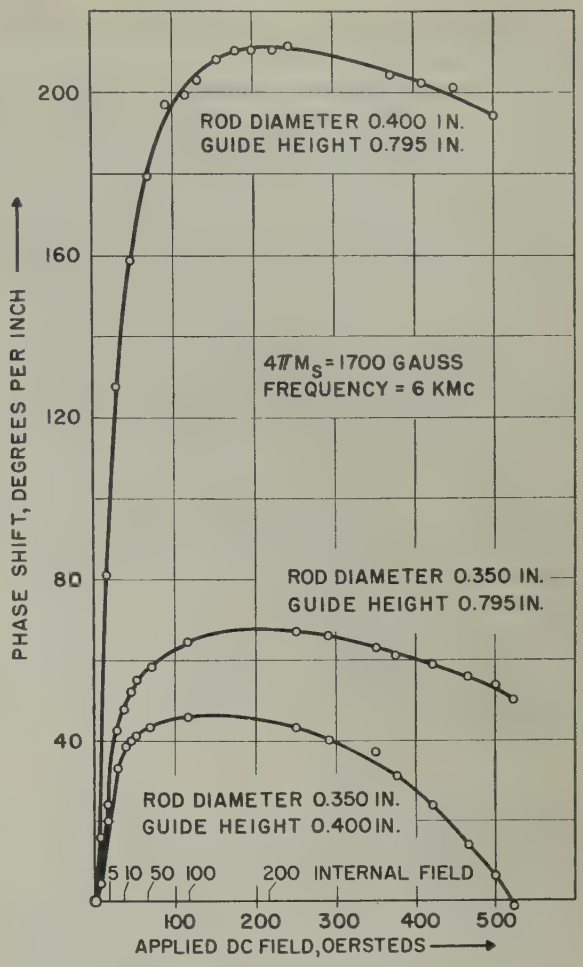

Fig. 2—The Reggia-Spencer phase shifter: observed phase shift in three structures as functions of applied dc field. The internal field values are estimated from the magnetization curve of the ferrite; the rods are 5 inches long.

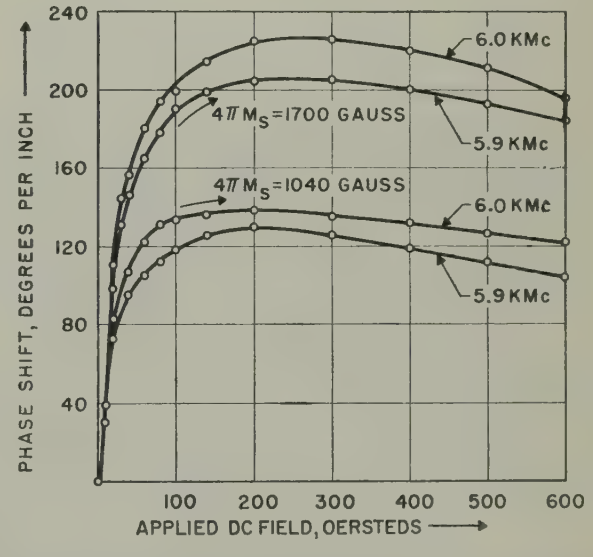

Fig. 3—The Reggia-Spencer phase shifter: observed phase shift as a function of applied dc field, showing dependence on frequency and saturation magnetization.

dielectric-waveguide effect is strong, the composite ferrite-air-metal structure can support only a single, elliptically polarized mode. Beyond a certain critical rod diameter, a second mode, also elliptically polarized, breaks into propagation, and the device exhibits the properties of a more or less elliptical Faraday rotator, becoming useless as a phase shifter due to the large fluctuations in transmission (although the phase shift is still present). Thus the operating range of the device can be specified (by an appropriate combination of frequency, ferrite diameter, and waveguide dimensions) as extending from the onset of the dielectric waveguide effect to the onset of rotation, the total amount of available phase shift becoming progressively larger from the former to the latter limit. In that range the conditions for coupling from the dominant mode in empty guide into the propagating mode on the rod appear to be peculiarly favorable. A full explanation of this will have to wait for more detailed analysis of the modes, but it is undoubtedly related to the curious fact that the two normal modes in the loaded section, one propagating and the other cut off, have the *same* sense of elliptic polarization.

Theory

To analyze the structure, we begin by neglecting entirely the geometrical details of the waveguide cross section and represent the radiation by plane waves. The anisotropic character of the rectangular waveguide is represented by a phenomenological tensor "dielectric" constant whose components may be adjusted to represent the role of the guide geometry in establishing the phase velocities in two mutually perpendicular polarizations. This model indicates the forms of the normal modes and their dependence on the magnetic parameters μ and κ as well as on the ellipticity of the structure. Following this, we perform a semiempirical comparison with the known solutions of a problem involving geometry which is similar to that of the phase shifter: namely, a circular dielectric rod on the axis of circular waveguide (the shielded dielectric waveguide)[7] in order to verify that the contribution of the variable-dielectric-waveguide effect is capable of accounting for the observed phase variations. Finally, we formulate some scattering relations for the structure under the assumed conditions, for comparison with the observed fluctuations in transmission.

In Maxwell's equations,

$$\text{curl } \boldsymbol{E} = -\overleftrightarrow{\mu}\frac{\partial}{\partial t}\boldsymbol{H}$$

$$\text{curl } \boldsymbol{H} = \overleftrightarrow{\epsilon}\frac{\partial}{\partial t}\boldsymbol{E} \tag{1}$$

assume for $\overleftrightarrow{\mu}$ Polder's form

$$\overleftrightarrow{\mu} = \begin{bmatrix} \mu & -i\kappa & 0 \\ i\kappa & \mu & 0 \\ 0 & 0 & \mu_0 \end{bmatrix} \tag{2}$$

and for $\overleftrightarrow{\epsilon}$ the diagonal form

$$\overleftrightarrow{\epsilon} = \begin{bmatrix} \epsilon_x & & \\ & \epsilon_y & \\ & & \epsilon_0 \end{bmatrix}. \tag{3}$$

Also assume

$$\frac{\partial}{\partial x} = \frac{\partial}{\partial y} = 0, \qquad \frac{\partial}{\partial t} = i\omega \tag{4}$$

for plane-wave propagation in the $\pm z$ directions at angular frequency ω. Combining the field equations (1) we obtain the system

$$\frac{d^2}{dz^2}\begin{bmatrix} E_x \\ E_y \end{bmatrix} = -\omega^2\begin{bmatrix} \mu\epsilon_x & -i\kappa\epsilon_y \\ i\kappa\epsilon_x & \mu\epsilon_y \end{bmatrix}\begin{bmatrix} E_x \\ E_y \end{bmatrix} \tag{5}$$

to be solved for the transverse components of the electric field $\boldsymbol{E}$. It is convenient to write (5) in the more general form

$$\frac{d^2}{dz^2}\begin{bmatrix} x \\ y \end{bmatrix} = \begin{bmatrix} a & b \\ c & d \end{bmatrix}\begin{bmatrix} x \\ y \end{bmatrix}. \tag{6}$$

The solutions of the characteristic equation

$$\lambda^2 - (a + d)\lambda + (ad - bc) = 0 \tag{7}$$

are the eigenvalues

$$\lambda_\pm = \tfrac{1}{2}(a + d) \pm \sqrt{\tfrac{1}{4}(a - d)^2 + bc}. \tag{8}$$

Let

$$\sigma_\pm = \tfrac{1}{2}(a \pm d)$$

and

$$R = (\text{sign of } \sigma_+)\sqrt{\sigma_-^2 + bc}; \tag{9}$$

then

$$\lambda_\pm = \sigma_+ \pm R. \tag{10}$$

The transformation S which diagonalizes the matrix of (6) is

$$S = \begin{bmatrix} \sigma_- + R & -b \\ c & \sigma_- + R \end{bmatrix}. \tag{11}$$

Let

$$\gamma_\pm = +\sqrt{\lambda_\pm} \tag{12}$$

denote the propagation constants. Then the normal modes $p(z)$ and $n(z)$ of the system (6) are

$$p = e^{\pm\gamma_+ z}, \qquad n = e^{\pm\gamma_- z}. \tag{13}$$

[7] See, for example, S. A. Schelkunoff, "Electromagnetic Waves," D. van Nostrand Co., Inc., New York, N. Y., sec. 10.20; 1943. Also, R. E. Beam and H. M. Wachowski, "Shielded dielectric-rod waveguides," *Trans. AIEE*, vol. 70, pp. 874–880; May, 1951. The data appropriate to the present problem are from Seidel and Brannon. (see footnote 9).

Transforming back again by means of S, we obtain $x(z)$ and $y(z)$, which may be conveniently expressed in the following form:

$$\begin{bmatrix} x \\ y \end{bmatrix} = U_+ \begin{bmatrix} X_+^0 \\ Y_+^0 \end{bmatrix} + U_- \begin{bmatrix} X_-^0 \\ Y_-^0 \end{bmatrix} \tag{14}$$

where $X_\pm^0$ and $Y_\pm^0$ are constants of integration and

$$U_\pm = \begin{bmatrix} \tau_+ e^{\pm\gamma_+ z} + \tau_- e^{\pm\gamma_- z} & \dfrac{b}{2R}\left(e^{\pm\gamma_+ z} - e^{\pm\gamma_- z}\right) \\ \dfrac{c}{2R}\left(e^{\pm\gamma_+ z} - e^{\pm\gamma_- z}\right) & \tau_- e^{\pm\gamma_+ z} + \tau_+ e^{\pm\gamma_- z} \end{bmatrix} \tag{15}$$

in which

$$\tau_\pm = \frac{1}{2}\left(1 \pm \frac{\sigma_-}{R}\right). \tag{16}$$

Returning to the original system (5), we have for the eigenvalues,

$$\lambda_\pm = -\omega^2\left[\tfrac{1}{2}\mu(\epsilon_x + \epsilon_y) \pm \sqrt{\tfrac{1}{4}\mu^2(\epsilon_x - \epsilon_y)^2 + \epsilon_x\epsilon_y\kappa^2}\right]. \tag{17}$$

It is convenient to introduce the combinations

$$\epsilon = \tfrac{1}{2}(\epsilon_x + \epsilon_y), \qquad \delta = \tfrac{1}{2}(\epsilon_x - \epsilon_y). \tag{18}$$

Then

$$\lambda_\pm = -\omega^2\left[\mu\epsilon \pm \sqrt{\mu^2\delta^2 + \kappa^2(\epsilon^2 - \delta^2)}\right]. \tag{19}$$

With the aid of (19) we distinguish the various ranges of operation, which may be expressed in terms of the ellipticity parameter δ. The case $\delta = 0$ corresponds to circular symmetry. For $\delta > 0$ but sufficiently small that both λ_+ and λ_- are negative, two elliptically polarized modes can propagate, and the structure exhibits the properties of an elliptical Faraday rotator. At $\delta = \epsilon$ one of the modes, namely $n(z)$ in the notation of (13), goes into cutoff; the range of δ appropriate to the phase shifter begins at this point. The device is observed to produce phase shift most copiously under the condition that δ exceeds ϵ only slightly; hence the term $(\epsilon^2 - \delta^2)\kappa^2$ in (19) is ordinarily small and negative. This means that the off-diagonal component κ of the Polder tensor has lost the central role it plays, for example, in the Faraday rotator: the forms of the x- and y-polarized components of the radiation have become so dissimilar because of the ellipticity of the structure that coupling between them has become a secondary effect. Neglecting the term in κ for the moment, we obtain as the eigenvalue for the propagating mode $p(z)$ the simple form

$$\lambda_\pm \cong -\omega^2\mu\epsilon_x. \tag{20}$$

The observed properties of the phase shifter are to be explained in terms of the magnetic parameter μ and the combined dielectric and geometrical parameter ϵ_x.

The forms of the elliptically polarized normal modes $p(z)$ and $n(z)$ may be deduced from S, (11). They are given by

$$\begin{bmatrix} x \\ y \end{bmatrix} = S \begin{bmatrix} p \\ n \end{bmatrix} = \begin{bmatrix} (\sigma_- + R)p - bn \\ cp + (\sigma_- + R)n \end{bmatrix} \tag{21}$$

where

$$\begin{aligned} \sigma_+ &= -\omega^2\mu\epsilon \\ \sigma_- &= -\omega^2\mu\delta \\ R &= (\text{sign of } \sigma_+)\omega^2\sqrt{\mu^2\delta^2 + \kappa^2(\epsilon^2 - \delta^2)} \\ b &= i\omega^2\kappa\epsilon_y = i\omega^2\kappa(\epsilon - \delta) \\ c &= -i\omega^2\kappa\epsilon_x = -i\omega^2\kappa(\epsilon + \delta). \end{aligned}$$

In Fig. 4 the modes are shown schematically in four special cases: $\delta/\epsilon = 0$, 1/2, 1, and 3/2. The values $\mu = 1$ and $\kappa = -1/2$ have been assumed. The rectangles in the figure represent the relative magnitudes of the major and minor axes of the guide cross section. The dashed ellipse in Fig. 4(d) indicates that the mode n is in cutoff.

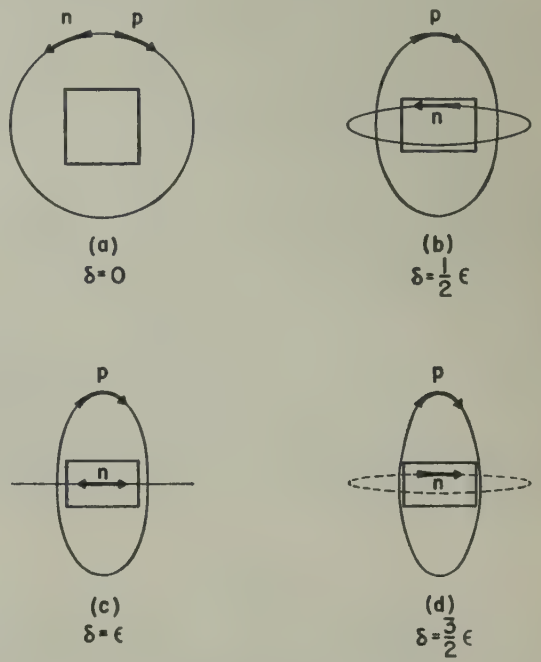

Fig. 4—The normal modes $p(z)$ and $n(z)$ in four special cases. The ellipses represent the electric field amplitudes, and the arrows indicate the senses of elliptic polarization. The rectangles represent schematically the degree of ellipticity. The dashed ellipse in (d) indicates that the mode n is in cutoff.

The Anomalous Variation of μ in the Unsaturated Ferrite

Fig. 5 illustrates[8] the dependence of μ on (internal) dc field, showing an abrupt increase at very low fields. No such effect is predicted by Polder's form[5] for μ if the magnetization M and internal field H are assigned their mean values over the body of the partially magnetized

[8] The data of Fig. 5 were furnished by E. Kankowski, using a system designed by J. H. Rowen for measurement of the tensor permeability. See W. von Aulock and J. H. Rowen, "Measurement of dielectric and magnetic properties of ferromagnetic materials at microwave frequencies," *Bell Sys. Tech. J.*, vol. 36, pp. 427–448; March, 1957.

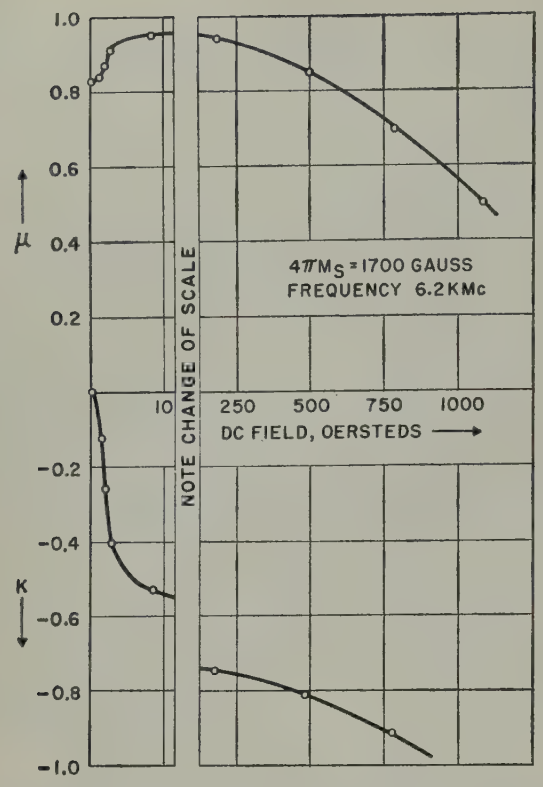

Fig. 5—The components μ and κ of the permeability tensor as functions of internal dc field, at 6.2 kmc on polycrystalline MgMn ferrite of saturation magnetization $4\pi M_s = 1700$ gauss.

ferrite. A more appropriate averaging process is to form the mean value of the product MH, thus incorporating the strong correlation[6] between the two factors. The result depends on the detailed crystallographic structure of the material, but in any case for the unmagnetized material μ takes the form

$$\mu \cong 1 - \frac{\gamma^2}{\omega^2} N_0 M_s^2 \tag{22}$$

where γ is the gyromagnetic ratio ($\sim$2.8 mc per oersted for electrons), M_s is the saturation magnetization, and N_0 is a mean effective demagnetizing factor which can be evaluated empirically. The value of N_0 deduced from the data of Fig. 5 is 3.7, corresponding to a mean internal field of about 500 oersteds. When the field is applied, the magnetization becomes more orderly and the internal field declines at first, leading to the observed form of μ.

The Variable-Dielectric-Waveguide Effect

The sensitivity of μ to the detailed structure of the ferrite leads to a variation which is in the right direction to contribute to an increase in phase on application of the dc field. The other contribution, which is represented in our schematic model by an increase in ϵ_x, is what we have termed the variable-dielectric-waveguide effect. As μ increases, the effectiveness of the ferrite rod as a dielectric waveguide improves, the radiation crowds into the rod, and the wavelength decreases. Fortunately a means for estimating the magnitude of this effect exists in the form of calculations on rods of dielectric constant $\epsilon = 10$ in circular waveguide.[9] The data of particular interest are the curves shown in Fig. 6 giving the guide wavelength and its rate of variation with increase in dielectric constant as functions of the rod diameter. The curves refer to the dominant mode (HE_{11}). The amount of dielectric loading of the guide is represented by the ratio of radii of the rod and waveguide, denoted by c. The numerical calculation referred to[9] includes an assumed value of 0.4 for the ratio of guide radius to free-space wavelength. The solid curve gives the ratio of free-space wavelength λ_0 to guide wavelength λ_g as a function of c. The dashed curve represents the rate of variation of guide wavelength with dielectric constant in the neighborhood of $\epsilon = 10$; the quantity plotted, denoted by L, is the log-log derivative $d(\log \lambda_0/\lambda_g)/d(\log \epsilon) = (\epsilon\lambda_g/\lambda_0)d(\lambda_0/\lambda_g)/d\epsilon$.

An empirical correlation of these theoretical results with the phase shift data of Fig. 2 can be obtained by observing the wavelength on the unmagnetized rod in the phase-shifter structure and assigning an effective rod diameter which yields the same wavelength in the circular case (reading from the solid curve of Fig. 6). We find the following from some typical observations:

frequency	6000 mc	
free-space wavelength λ_0	5 cm (1.97 inches)	
waveguide dimensions	1.590×0.795 inch	
material	MgMn ferrite, $4\pi M_s = 1700$ gauss	
rod	rod *A*	rod *B*
diameter	0.350 inch	0.400 inch
wavelength λ_g at $H=0$	1.89 inches	1.52 inches
λ_0/λ_g	1.04	1.29
loading ratio c	0.25	0.27

Note that the amount of ferrite filling is sufficient to reduce the guide wavelength below that for free space; that is, $\lambda_0/\lambda_g > 1$. The condition $\lambda_0/\lambda_g = 1$ is a critical point in the theory of shielded dielectric waveguide at which the dielectric rod first takes over from the shield the dominating influence in confining the radiation. Now with the values of c thus deduced, we read in Fig. 6 the corresponding values of the derivative L:

rod	rod *A*	rod *B*
L, predicted	0.85	1.06

These values of L constitute a predicted value of the rate of increase in phase of the structure with increase in the effective dielectric constant of the rod, deduced from the theory with the aid of the observed wavelength in the unmagnetized state. In order to compare the prediction with an observed rate of phase shift, we must make the following, somewhat questionable, assumption: that the product $\mu\epsilon$ in the present problem

[9] H. Seidel, unpublished work on shielded dielectric-rod waveguide, with computations by M. J. Brannon; 1954.

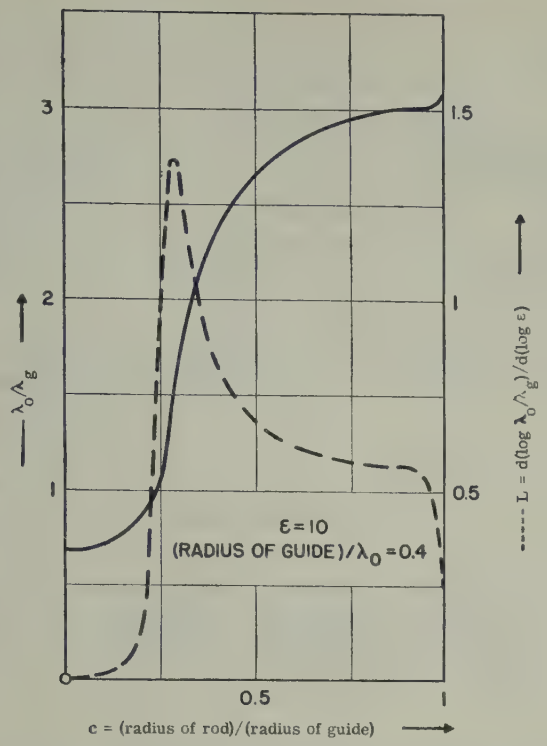

Fig. 6—Guide wavelength and its variation with dielectric constant in shielded dielectric-rod waveguide.[9]

can be identified with the parameter ϵ in the dielectric-waveguide theory. Although the assumption is strictly justifiable only in the case of plane waves, to which the dielectric-rod considerations are obviously inapplicable, nevertheless, it is no worse than consistent with the approximate nature of our development; no worse, certainly, than the correlation established above between rectangular and circular guide. The forms of the (exact) characteristic equations for shielded and unshielded dielectric waveguide[7] suggest that the approximation is reasonable, especially for the large value of ϵ with which we are concerned.

The observed variation of phase (Fig. 2) and of μ (Fig. 5), as functions of the internal dc field (that is, adjusted for demagnetizing effects) have more or less uniform slopes over the range of internal fields in which the most rapid phase change occurs. From these slopes, we deduce representative values of the rate of change of guide wavelength with μ and thence empirical values for the logarithmic derivative L, to be compared with the predicted values noted in the previous paragraph. Denoting phase shift per unit length by ϕ and internal dc field by H, we obtain

$d\mu/dH$		0.107 oersted^{-1}
rod	rod A	rod B
$d\phi/dH$	14	24° inches^{-1} oersted^{-1}
L, empirical	0.69	0.95
L, predicted	0.85	1.06

Comparing these empirical values of L with those predicted above, we note that the agreement is reasonable, considering the many approximations involved. It is illuminating to observe that the above comparison of values of L shows the amount of phase shift available in the device (which appeared at the outset to be unaccountably large) to be actually somewhat less than predicted. We may not be justified in putting a physical interpretation on these small differences at this rudimentary stage in the theory, but it is a fact that the term $\kappa^2(\epsilon^2-\delta^2)$ in the propagation constant γ_+, which we have neglected [see (19) and (20)], does tend to reduce the phase shift. The two lower curves in Fig. 2 show the reduction which results when the difference $|\epsilon^2-\delta^2|$ is increased by reducing the height of the guide.

Scattering in Phase Shifter and Rotator Structures

Simple qualitaive expressions for the scattering by the structure in the two cases $\delta<\epsilon$ (elliptical Faraday rotator) and $\delta>\epsilon$ (phase shifter) may be derived in the following way. We describe the input and output planes of the loaded section by a phenomenological scattering matrix of appropriate form and solve for the steady state under excitation by a wave of unit amplitude incident from one direction. The calculation is a straightforward generalization of the analysis of the interference effect in the Faraday rotator.[4] In the phase shifter case, where the structure supports only a single propagating mode, associated with the propagation constant γ_+, we are justified in neglecting the evanescent waves associated with γ_- provided they are attenuated appreciably in a distance which is short compared to the length of the structure. Observations of the frequency dependence of transmission show that this condition is fulfilled everywhere except very close to the limiting case $\delta=\epsilon$. With this simplification, the matrices $U_\pm$ of (15) reduce to

$$U_\pm = e^{\pm\gamma_+ z}\begin{bmatrix} \tau_+ & \dfrac{b}{2R} \\ \dfrac{c}{2R} & \tau_- \end{bmatrix}. \tag{23}$$

Then the scattering calculation leads to the following expression for the amplitude E of the transmitted wave:

$$E = \left[\frac{s's\tau_+}{1-(r'\tau_+ + t\tau_-)^2 e^{-2\gamma+d}}\right] e^{-\gamma+d} \tag{24}$$

where d is the length of the structure and s, s', r', t are scattering coefficients referring to the terminal planes. Of these, s, s', r' define respectively inward transmission, outward transmission, and internal reflection of radiation polarized in the x direction (the polarization for propagation in empty guide), and t defines internal reflection of radiation polarized in the y direction. The resonance described by the denominator in (24) accounts for the undulations in transmission discussed earlier

when reasonable values are assigned to the coefficients. Of the two scattering coefficients, r' and t, appearing in the denominator, r' can be made arbitrarily small by the addition of matching elements, as mentioned earlier, but the term containing t represents a residual mismatch which cannot be removed by this means, since it describes the full reflection of cross-polarized radiation at the ends of the loaded section.

In the rotator case, the presence of two propagating modes complicates the problem; the most conspicuous feature is the appearance of the interference effect[4] which produces violent, frequency-dependent fluctuations in transmission. The matrices $U_\pm$ become

$$U_\pm = e^{\pm i\beta z}\begin{bmatrix} \cos\rho z \mp i\dfrac{\sigma_-}{R}\sin\rho z & \pm i\dfrac{b}{R}\sin\rho z \\ \pm i\dfrac{c}{R}\sin\rho z & \cos\rho z \pm i\dfrac{\sigma_-}{R}\sin\rho z \end{bmatrix} \quad (25)$$

where

$$\gamma_\pm = i\beta_\pm$$
$$\beta = \tfrac{1}{2}(\beta_- + \beta_+), \qquad \rho = \tfrac{1}{2}(\beta_- - \beta_+).$$

The transmission E now takes the form

$$E = \frac{1}{\Delta}s'se^{-i\beta d}\left[(1 - t^2e^{-2i\beta d})\cos\rho d + \frac{i\sigma_-}{R}(1 + t^2e^{-2i\beta d})\sin\rho d\right] \quad (26)$$

where the denominator Δ is a long expression describing coupled resonances in the x and y polarizations. If the structure is well matched at zero applied field, the effect of Δ is secondary. The factors $(1 \pm t^2e^{-2i\beta d})$ describe the interference effect.

An illuminating picture of the two cases (24) and (26) emerges when the structure is viewed over a range of frequencies including the point where δ and ϵ are equal; that is, where the second mode first breaks into propagation. Examples of such a picture as presented by a swept-frequency test circuit are shown in Fig. 7. The quantity displayed is $|E|^2$ over the frequency range 5730 to 6310 mc. The structure is composed of a ferrite rod of saturation magnetization $4\pi M_s = 1700$ gauss, 0.400 inch diameter $\times 5$ inches long, mounted in standard WR-159 guide.

Fig. 7(a) shows the transmission at zero magnetization. Only the broad undulations in transmission are visible. The insertion loss varies between 0.8 and 1.3 db over the band. On application of the dc field, a number of additional features abruptly appear, as shown in Fig. 7(b), where the applied field is 14 oersteds. The transitional point T at which $\delta = \epsilon$ occurs at 6122 mc. On the low frequency (phase shifter) side of T the undulations persist, with some increase in amplitude and shortening of "wavelength." [For clarity, the undulations have been intentionally made rather large by

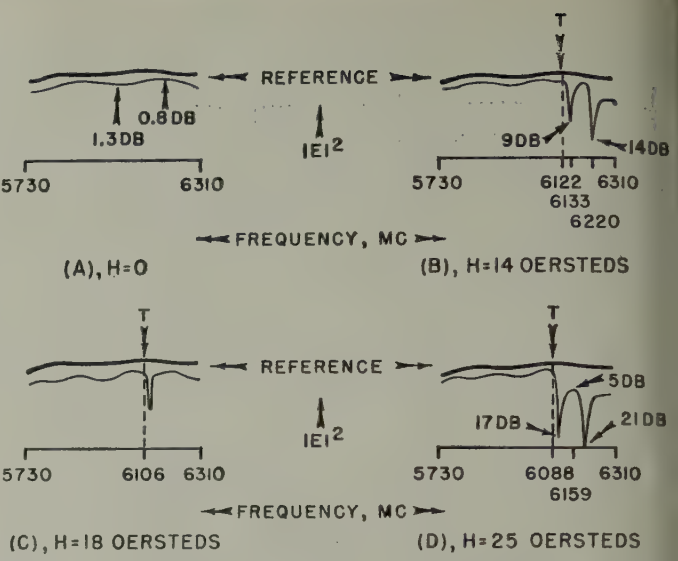

Fig. 7—Swept-frequency presentation of the transmission $|E|^2$ of the Reggia-Spencer phase shifter, showing the transition from the phase shift region at frequencies less than T to the rotator region at frequencies greater than T. The insertion loss values, in decibels, are those referred to in the text.

using a somewhat oversized rod with flat ends. The decrease in "wavelength" on increase of the applied field is, of course, a measure of the increase in phase, as indicated by (24).] The interference "spikes" are visible on the high-frequency (rotator) side of T: one very close to T, at 6133 mc, and the next at 6220 mc. With further increase in applied field, the spikes alternately disappear [Fig. 7(c), 18 oersteds] and reappear [Fig. 7(d), 25 oersteds] as the Faraday rotation [measured by ρd in the notation of (25)] passes through successive multiples of 90°. The motion of the point T on the frequency scale reflects the variable-dielectric-waveguide effect: as the radiation concentrates in the ferrite rod, the constraint imposed by the waveguide walls is gradually relieved, and cutoff for the mode $n(z)$ moves to lower frequencies. In Fig. 7(b), 7(c), and 7(d), the point T is at 6122, 6106, and 6088 mc, respectively. On account of the ellipticity of the structure, the insertion loss in the rotation regions between the interference spikes is limited to about 5 db, as for example at 6159 mc in Fig. 7(d). The spikes themselves reach successively higher insertion loss values at each reappearance, thereby reflecting the anticipated diminution of "low field loss" effects;[6] the two spikes in Fig. 7(b) reach 9 and 14 db, but those in Fig. 7(d) reach 17 and 21 db.

Conclusions

The correspondence between the highly simplified phenomenological model and the behavior of the Reggia-Spencer phase shifter serves to explain the *modus operandi* of the device. It also accounts for a number of the finer details in the observations. Further systematic study of the structure will enable us to establish numerical correlations between the phenomenological parameters, such as δ and ϵ, and the geometrical details, so

hat in subsequent development work, we shall be in an dvantageous position to interpret the data, distinguish etween significant and secondary effects, etc. Ultiately, if necessary, the composite cross section of the tructure may be subjected to analysis of a higher degree f approximation or to exact numerical treatment in he practical cases of greatest interest. The present nalysis of the propagating and nonpropagating modes heds some light on the question of Faraday rotation ubject to elliptic waveguide symmetry. It also sugests ways of coupling into and out of the modes for the urpose of producing other novel effects.

Acknowledgment

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A New Look at the Phase-Locked Oscillator*

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Summary—**The uses of phase-locked oscillators are briefly reviewed. A simple automatic-phase-control (APC) system is analyzed as a servomechanism analog. Three major characteristics of the system are considered: the lock range, the capture range, and the filter bandwidth. The lock range is the total drift in the unlocked oscillator frequency which can be exactly compensated by the locked system. The capture range is the largest unlocked frequency difference at which synchronization, or lock-in, will occur. The filter bandwidth of the system expresses the performance of the system as a low-pass filter with respect to FM noise components existing in the input to the system and as a high-pass filter with respect to FM noise components generated within the output oscillator.**

The mutual interdependence of these characteristics and the various quantities affecting each one are discussed. The conditions for stable operation of the system are established. The unlocked, locking-in, and locked conditions of operation and the effects of the low-pass filter are discussed. Simple design criteria are established.

Introduction

THE phase-locked oscillator system has been analyzed many times in the past.[1–7] Most of these analyses have been in classical mathematical terms. In this paper the author is attempting a new approach to the problem, utilizing concepts which are well understood by people familiar with servomechanism and feedback system design. It is hoped that this approach will produce a clearer understanding of the system, both qualitative and quantitative.

Uses of Phase-Locked Oscillators

There are many varied uses for a phase-locked oscillator or automatic-phase-control (APC) system as it is sometimes called. An APC system can be used in a receiver to increase the power level and attenuate the noise of a weak FM signal. A similar system, involving somewhat different design parameters, can be used to reduce the jitter or frequency noise of a high-powered oscillator. In the field of frequency measurement and synthesis, in particular, the APC system is extremely useful.

Many frequency measurement and synthesis systems involve the generation and selection of a single frequency signal. Because of the generation process, a poor signal-to-noise ratio (SNR) results—the noise in this case taking the form of adjacent frequency components (or sidebands) and small deviation FM or phase jitter of the desired component. A phase-locked oscillator can serve as a filter of arbitrarily narrow bandwidth (arbitrarily high Q) for the selection of the desired signal, attenuating the unwanted components and reducing the phase jitter.

Description of a Phase-Locked Oscillator System

Fig. 1 shows the basic components of an elementary APC system. There are many ramifications of this basic system, some using frequency dividers or multipliers,

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[1] R. Ley, "Phase synchronization of an oscillator, application to a continuously variable oscillator of high stability," *Ann. Radioelec. (Paris)*, vol. 13, pp. 212–233; July, 1958.

[2] T. J. Rey, "Effects of the Filter in Oscillator Synchronization," Lincoln Lab., M.I.T., Lexington, Mass., Tech. Rep. No. 181 (ASTIA 133854); May, 1958.

[3] R. Leek, "Phase-lock A.F.C. loop, tracking signals of changing frequency," *Electronic and Radio Engr.*, vol. 34, pp. 114 and 177; April and May, 1957.

[4] D. Richman, "Color-carrier reference phase synchronization accuracy in NTSC color television," PROC. IRE, vol. 42, pp. 106 and 288; January, 1954.

[5] W. J. Gruen, "Theory of A.F.C. synchronization," PROC. IRE, vol. 41, pp. 1043–1049; August, 1953.

[6] G. W. Preston and J. C. Tellier, "The lock-in performance of an A.F.C. circuit," PROC. IRE, vol. 41, pp. 249–251; February, 1953.

[7] E. Labin, "Theory of synchronization by control of phase," *Phillips Res. Rep.* vol. 4, pp. 291–315; August, 1949.

and some using offset comparison frequencies; but we shall restrict our attention to the simple system shown here. No great generality will be lost by this procedure. The system contains: an oscillator with a nominal frequency equal to the desired output frequency; some form of reactance modulator or other means for voltage control of the oscillator frequency; a phase detector which compares the outputs of the oscillator and the reference source; and a low-pass filter which filters the output voltage of the phase detector before it is applied to the reactance modulator.

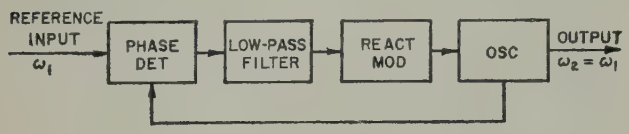

Fig. 1—Block diagram: automatic phase-control system.

The operation of the system can be understood qualitatively by assuming that the oscillator frequency is equal to that of the reference. The phase-detector output is then a dc voltage dependent on the phase difference between the output signals of the oscillator and the reference. This voltage is applied through the low-pass filter to the reactance modulator and thereby governs the oscillator frequency. If the oscillator frequency tends to change, this attempted change is first felt as a phase-difference change in the phase detector. This produces a change in phase-detector output voltage which acts to hold the oscillator frequency constant. As the oscillator drifts, its output phase, relative to that of the reference, will drift, but its average frequency will remain fixed. The system operates exactly like a positional servomechanism wherein, for constant input position, the output position is exactly equal to the input, with zero steady-state error.[8] To understand the lock-in performance of the system and its quantitative behavior with respect to noise and drift requires a closer look.

Servo Analysis of a Phase-Locked Oscillator

A block diagram of the simple phase-locked oscillator system, which lends itself more readily to analysis, is shown in Fig. 2. This block diagram, incidentally, is identical to that for a positional servo. The circled Σ's represent summation points where various signal variables (voltages or frequencies) are combined. Frequency noise (incidental FM or jitter) contributed by the reference source is represented by N_1. The $1/S$ term represents the integration of frequency difference to phase difference which occurs in the phase detector. It is this integration which gives the system its unique properties and distinguishes it from the more familiar automatic-frequency-control (AFC) system. In an AFC system, the frequency of the oscillator is compared to a reference frequency. For example, the resonant frequency of a passive circuit, and the frequency difference—not phase difference—is used to generate a signal which tends to reduce the frequency difference. Such a system requires a small, but finite, error of the controlled variable (the output frequency) in order to operate. The phase-lock system, on the other hand, requires no steady-state error of the controlled variable, but instead utilizes an error in the *integral* of the controlled variable, *i.e.*, an error in phase difference. The gain of the phase detector in volts per radian is represented by K_1. The frequency characteristic of the low-pass filter is indicated by $F(S)$, and K_2 represents the gain of the reactance-modulator-oscillator combination in radians per second, per volt. N_2 represents noise voltage at the input to the reactance modulator, and Ω includes both the detuning of the oscillator and frequency noise in its unlocked output.

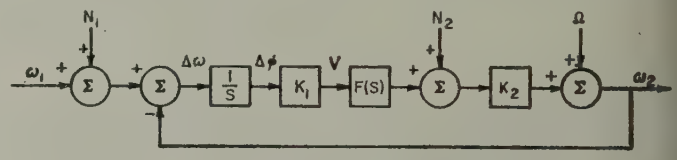

Fig. 2—Servo block diagram.

Lock Range

There are several quantities of interest for this system. Among the most important are the lock range, the capture range, and the filter bandwidth. From a knowledge of these quantities, much of the behavior of the system can be calculated, such as the static phase error, the response to an input transient, etc. The lock range is the total drift in unlocked output frequency which can be exactly compensated by the system. For a multiplier or divider system, the lock range is usually chosen so that all expected drifts in the oscillator frequency due to component changes and ambient temperature variations can be compensated as the phase-detector output traverses its entire range. From Fig. 2 it can be seen that the lock range is equal to the range of the reactance-modulator-oscillator combination caused by the maximum voltage range of the phase detector. For a linear reactance modulator and a linear phase detector operating over a range of π radians, the lock range would equal $\pi K_1 K_2$ radians per second. That is, a phase-difference change of π radians produces a voltage change of πK_1 volts out of the phase detector, which in turn produces a change of $\pi K_1 K_2$ radians per second in the frequency of the reactance-modulator-oscillator combination. For a linear reactance modulator and a typical nonlinear balanced phase detector, however, which has a maximum output swing of $2K_1$ volts, the lock range would be $2K_1 K_2$ radians per second.

A given total lock range can be achieved with a large K_1 and a small K_2 or vice versa. Whichever gain should

[8] H. Chestnut and R. Mayer, "Servomechanisms and Regulating System Design," John Wiley and Sons, Inc., New York, N. Y.; 1950 and 1955.

made larger depends on the noise susceptibilities of e various components. Since, in a practical system, e input to the reactance modulator is usually the most ise-sensitive point in the system, a large K_1 and a all K_2 are desirable. This is achieved with a high- tput phase detector and a "stiff" reactance-modula- r-oscillator combination. Indeed, a "stiff" oscillator ffers many advantages in a system for removing phase odulation from the reference signal. An oscillator hose frequency is hard to pull usually has good long nd short-term stability and thus requires a smaller lock nge and produces a cleaner output than a "loose" scillator. For these reasons, a quartz crystal oscillator sometimes used at the output of a phase-locked ultiplier.

Capture Range

The capture range is the largest unlocked frequency difference at which the system will lock-in. This capture range cannot be larger than the lock range, but it can be smaller. To gain a clear understanding of the operation of the system, let us ignore for a time the low-pass filter. That is, let us assume that the cutoff frequency, ω_f, of this filter is greater than certain other frequencies of interest. The reason for this will be more apparent later. *For this condition the capture range is equal to the lock range.*

Fig. 3 is a diagram which aids in obtaining a physical picture of the operation of the system—both for the locked and the unlocked conditions. Oscillator frequency is plotted along the vertical axis, and phase difference is plotted along the horizontal axis. The curves represent the frequency of the oscillator as a function of oscillator-reference phase difference and repeat for every integral multiple of 2π. There exists a family of these curves, each one corresponding to a different rough tuning of the oscillator.

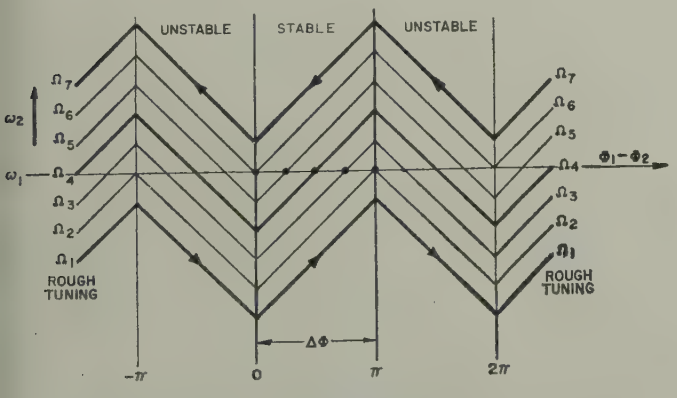

Fig. 3—Composite locking diagram.

In order for locking to occur, the rough tuning must be such that the oscillator frequency curve intersects the ω_1 line (*i.e.*, $\omega_2 = \omega_1$). Assume that Ω_4 in Fig. 3 represents the oscillator rough tuning. There are two possible intersections of the Ω_4 curve with the ω_1 line. Only one of these intersections is stable, the other intersection corresponding to a condition of positive rather than negative feedback. The stable intersection is indicated in Fig. 3. This intersection may be called the locked operating point and indicates the phase difference required to maintain lock (the static phase error). If the rough tuning is varied (or drifts) through Ω_3 to Ω_2, the oscillator will remain locked and the operating point will move toward one end of the stable region. If the rough tuning is varied still further, say to Ω_1, the oscillator will unlock and the operating point will move along the Ω_1 curve in the direction indicated by the arrows, producing continuous frequency modulation of the oscillator.

Now let us reverse the procedure. Assume that the oscillator tuning has been brought to Ω_1 from some far-distant value. Since the Ω_1 curve does not intersect the ω_1 line, locking is impossible and, as mentioned before, the operating point moves along the Ω_1 line. The nature of this motion can be understood qualitatively by the following physical argument. Since the frequencies of the oscillator and reference are not equal, the output of the phase detector is a beat voltage. The "frequency" of this beat will equal the difference between the oscillator and reference frequencies. When the operating point on the Ω_1 curve is in the region furthest removed from ω_1, the beat frequency is high and the operating point moves rapidly. When the operating point is in the region near ω_1, the beat frequency is low and the operating point moves slowly. The oscillator frequency "hesitates" for a time as it nears the reference frequency. Then it sweeps rapidly away and back again. Appendix II shows that, under these conditions, the output voltage of the phase detector is a series of back-to-back exponentials, with flat regions as the operating point hesitates near ω_1 and sharp cusps as the operating point moves rapidly down one side of the phase-detector characteristic and up the other. As the tuning is changed from Ω_1 toward Ω_2, the hesitation lasts longer and longer until, at Ω_2, the operating point stops, right at the edge of the lock range, and the oscillator is locked.

For the case considered, *i.e.*, neglecting the low-pass filter, it can be shown that the capture range is equal to the lock range.[7] That is, if the oscillator frequency vs phase-difference line intersects the desired frequency, the oscillator will lock at the stable point of intersection.

Filter Bandwidth

The filter bandwidth of the system represents its behavior as a "frequency noise" or "jitter" filter. This can be best expressed in terms of a cutoff frequency ω_c. It can be seen in Fig. 2 that the system behaves as a low-pass filter with respect to input noise N_1. That is, components of N_1 with rates below ω_c, *i.e.*, slowly varying changes in the reference frequency, appear directly in the output, whereas components with rates above ω_c are attenuated. Conversely, the system behaves as a high-pass filter with respect to internal noise N_2. That

is, components of N_2 with rates below ω_c are attenuated in the output, whereas components with rates above ω_c appear directly. This topic is discussed further in Appendix I.

In a narrow-band system, the output oscillator does not follow rapid excursions of the reference frequency such as rapid FM or jitter, but any internally generated rapid excursions appear directly. In a wide-band system, on the other hand, the output oscillator follows rapid excursions of the reference frequency, but internally generated rapid excursions are attenuated. Depending on the purposes of the system, whichever noise source is most objectionable determines whether ω_c should be made small (narrow band) or large (wide band). For example, if the purpose of the system is to select the long-term average of the input frequency and remove incidental FM or jitter existing in the reference, an inherently clean oscillator (such as a crystal oscillator) should be chosen and ω_c should be made as small as possible. On the other hand, if the purpose of the system is to reproduce the frequency excursions of the input[3] or to remove incidental FM in the output oscillator (such as a klystron oscillator), ω_c should be made as high as possible. *However, one is not free to adjust the bandwidth without, at the same time, affecting the lock range or the capture range.*

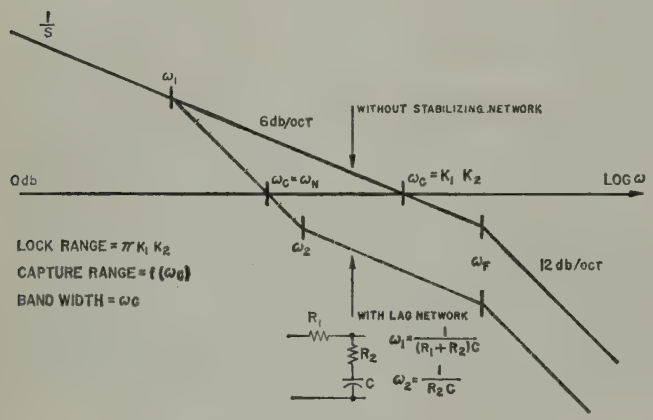

Fig. 4—Open loop gain.

Fig. 4 shows a plot of the open-loop gain of the system in decibels vs logarithmic frequency. Because of the $1/S$ integration term, the loop gain decreases with frequency at a rate of 6 db per octave, intersecting the zero-decibel (unity gain) line at a frequency $\omega_c = K_1K_2$. *This is the cutoff frequency of the closed-loop system.* That is, the transfer characteristic of the system equals unity ($\omega_2 = \omega_1$) for input variations with rates below ω_c and falls off for rates above ω_c. The low-pass filter is assumed to be a simple RC section with a cutoff frequency of ω_f (shown greater than ω_c). This filter causes an increase in the rate of open-loop and closed-loop attenuation to 12 db per octave above ω_f.

This open-loop gain-frequency diagram completely defines the characteristics of the system. The lock range is equal to πK_1K_2, the capture range is equal to the lock range, and the cutoff frequency ω_c is equal to K_1K_2. The static phase-error constant is $1/K_1K_2$ radians phase difference for each radian per second attempted frequency difference. Lock range, capture range, and bandwidth all increase in proportion to K_1K_2. Fortunately, this is often advantageous. A system for locking a klystron oscillator, for example, should have a large K_1K_2 to accommodate wide drift in the klystron frequency. A large K_1K_2 product automatically produces a desirable wide capture range and the wide bandwidth necessary for noise attenuation. Similarly, designing a system with small K_1K_2 to accommodate a crystal oscillator automatically produces a small capture range and a narrow bandwidth.

Effect of the Low-Pass Filter

Although the system bandwidth cannot be made greater than $1/\pi$ times the lock range, one might think that the bandwidth could be reduced by making the cutoff frequency, ω_f, of the low-pass filter lower than K_1K_2 but one has to be a little careful about this. Several changes occur as the filter cutoff frequency, ω_f, is lowered. The phase shift at the frequency at which the loop gain is unity gets closer to $\pi(180°)$, and the system transient response to a step input develops underdamped ringing.[9] Another important happening is a reduction of the capture range. The unlocked oscillator frequency must be brought nearer to the reference frequency than indicated by the lock range, for locking to occur. A hysteresis effect exists. For this case it can be shown that the reduction in capture range is approximately equal to the reduction in system bandwidth (unity-gain frequency) caused by a lowering of ω_f.[1,2]

A better method of narrowing the bandwidth involves the use of a lag (integral-compensation) network as the low-pass filter.[8] The effect of this network is shown in the dashed curve of Fig. 4. Such a network also reduces the capture range, but not as drastically as the simple RC filter discussed above. It can be shown that the use of a lag network with constants chosen to insure a minimum noise bandwidth (for the chosen system bandwidth) will produce a reduction in capture range approximately equal to the square root of the reduction in system bandwidth.[2,5] (See Appendix I.)

A reduction in capture range can possibly be tolerated if the operator of the system is required to lock the oscillator before use or if a nonlinear lag network[1] is used. However, such a system may be only conditionally stable. If the oscillator drifts outside the capture range —still remaining within the lock range—a small perturbation may cause it to unlock. The system is also conditionally stable in the sense that any nonlinearity or shift in K_1 or K_2 can cause the open-loop unity-gain frequency to move to an unstable region.

It is usually desirable to have the capture range as

[9] See Appendix I.

arly equal to the lock range as possible, to insure king whenever the oscillator tuning is within the lock nge. This requires a low-pass filter with a cutoff frequency greater than K_1K_2.

mmary

To summarize the foregoing results: The lock range the system in radians per second is equal to πK_1K_2, times the product of the gains of the phase detector id reactance-modulator-oscillator combination. The ndwidth of the system is determined by the cutoff equency, ω_c, the frequency at which the open-loop in falls to unity. This is equal to K_1K_2 in the absence a low-pass filter. The capture range of the system is function of the cutoff frequency, ω_c. With no low-pass lter, the capture range is equal to the lock range. With simple RC filter reducing ω_c, the capture range is educed by approximately the same factor. With an ptimized lag network reducing ω_c, the capture range is educed by approximately the square root of the bandidth reduction.

Design Procedure

The usual procedure is to design the best oscillator conomically feasible to produce the desired output frequency. The reactance modulator may be a reactance ube, a voltage-variable inductor or capacitor, or the ike. The phase detector may be a balanced type to reduce amplitude sensitivity or a simple tuned-circuit-iode rectifier if the amplitudes involved are constant. Use of a limiter is desirable since amplitude variations n the phase detector can result in frequency modulation f the output oscillator. The product K_1K_2, preferably vith large K_1 and small K_2, should be chosen to insure ocking for all expected drifts in oscillator or reference requency. For a maximum capture range, the low-pass ilter should have a cutoff frequency slightly greater han K_1K_2. If a wider bandwidth is desired to attenuate nternal noise, the lock range may be made greater than ecessary. This will also reduce the phase error required o correct a given frequency error.

If a small static phase error and a narrow bandwidth re desired and a reduction in capture range can be olerated, a lag network should be used.[9]

It should be emphasized that in actual practice the arameters, K_1 and K_2, may be variable. The common alanced phase detector, for example, has a sensitivity K_1) which depends on the phase-difference operating oint. Similarly, most reactance-tube controlled oscilators have sensitivities (K_2) which depend on the reactance-tube bias, the *O*-bias (high gm) region being the nore sensitive . Therefore, the bandwidth and stability nay vary with the lock operating point. All possible alues of K_1 and K_2 should be considered in the design.

Ordinarily K_1, K_2, and the low-pass filter characteristic are chosen for the best compromise with respect to ock range, capture range, static phase error, transient esponse to input signal variations, input noise rejection, internal noise rejection, and economy, for the particular application. Often a great deal of subjective experimenting is required. The criteria mentioned above should serve as a useful guide, however.

Conclusion

In conclusion, the phase-locked oscillator is a versatile device. It can be used to increase the power level and SNR of a weak, jittery signal or to reduce short-term frequency excursions of either the reference source or the oscillator itself. The techniques described have been used successfully to multiply standard frequencies from 100 kc to 1 mc, 5 mc, 10 mc, and 100 mc with locked crystal oscillators, and to 1000 mc with a locked klystron oscillator.[10,11]

Appendix I

Analysis of the Low-Pass Filter Effect

System Transfer Function: In Fig. 2, let the transmission of the low-pass filter be:

$$F(s) = \frac{1 + t_2 s}{1 + t_1 s} . \tag{1}$$

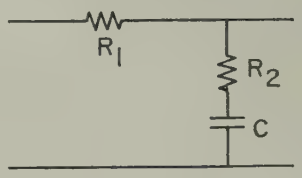

Fig. 5—Lag-network.

This corresponds to the use of a lag network shown in Fig. 5, where

$t_1 = (R_1 + R_2)C$ = the time constant of the lag break
$t_2 = R_2C$ = the time constant of the lead break.

The transfer function of the system can be calculated to be:

$$\frac{\omega_2(s)}{\omega_1(s)} = \frac{K(1 + t_2 s)}{t_1[s^2 + s(1/t_1 + Kt_2/t_1) + (K/t_1)]} . \tag{2}$$

where $K = K_1K_2$.

The denominator is of the general form

$$s^2 + 2\zeta\omega_n s + \omega_n^2,$$

where

$$\omega_n = \text{the natural resonant frequency} = \sqrt{\frac{K}{t_1}} \tag{3}$$

$$\zeta = \text{the damping ratio} = \frac{1 + Kt_2}{2\omega_n t_1} . \tag{4}$$

[10] J. K. Clapp and F. D. Lewis, "A unique standard-frequency multiplier," 1957 IRE National Convention Record, pt. 5, pp. 131–136.

[11] F. D. Lewis, "New standard frequency multipliers," *General Radio Experimenter*, vol. 32, pp. 3–9; July, 1958.

It will be shown later that ω_n equals ω_c, the open-loop crossover frequency.

Noise Bandwidth: The response of the system to random disturbances on the input can be expressed in terms of its noise bandwidth:[1,2,5]

$$F_n = \int_0^\infty \left| \frac{\omega_2}{\omega_1}(j\omega) \right|^2 d\omega. \tag{5}$$

This is the area under the square of the closed-loop frequency response curve.

Eq. (2) can be substituted in (5) and the integration carried out to yield[1,2,5]

$$F_n = \frac{\pi\omega_n}{4\zeta}\left[1 + \left(2\zeta - \frac{\omega_n}{K}\right)^2\right], \tag{6}$$

or, in terms of $\alpha = t_1/t_2 =$ the network ratio,

$$F_n = \frac{\pi}{2} K \frac{\alpha^2 + Kt_1}{\alpha^2 + \alpha K t_1}. \tag{7}$$

For the minimum noise bandwidth, it can be shown that the following conditions should be satisfied:[2]

$$\zeta_0 = \frac{1}{2}\sqrt{1 + \left(\frac{\omega_n}{K}\right)^2}, \tag{8}$$

or, in terms of α,

$$\alpha_0 = 1 + \sqrt{1 + Kt_1} = 1 + \sqrt{1 + \left(\frac{K}{\omega_n}\right)^2}. \tag{9}$$

These equations can be manipulated to yield the following relationship between the several frequencies of interest:

$$\left(\frac{1}{t_2\omega_n}\right)^2 = 1 + \frac{2}{Kt_1}\left[1 + \sqrt{1 + Kt_1}\right]. \tag{10}$$

The left side of this equation is the square of the ratio of the network lead frequency to the resonant frequency. According to the right side, this ratio can never be less than one. This indicates that, in a system with minimum noise bandwidth and for the usual case $K > (1/t_1)$, the resonant frequency $\omega_n = \sqrt{K/t_1}$ equals ω_c, the open-loop crossover frequency, and the crossover frequency occurs in the 12-db-per-octave region of the open-loop gain.

Limiting Cases: With no low-pass filter at all, the noise bandwidth becomes:

$$F_n = \frac{\pi}{2} K \tag{11}$$

This can be seen from (5) by letting $\alpha = 1$.

Similarly, with a single-section RC filter

$$F_n = \frac{\pi}{2} K. \tag{12}$$

This can be seen by letting α approach infinity in (5).

This last result is interesting since it shows that as the crossover frequency, $\omega_c = \sqrt{K/t_1}$, is lowered by increasing t_1, the damping ratio decreases so as to maintain the noise bandwidth constant at $\pi/2K$. In other words, as the crossover frequency is lowered, the peaking of the frequency response curve is increased, maintaining the area under the square of this curve constant.

With the use of the optimized lag network mentioned, the noise bandwidth varies from $\pi/2\omega_c$ for $\omega_c = K$ to $\pi\omega_c$ for $\omega_c \ll K$. The optimum value of ζ varies from 0.707 for $\omega_c = K$ to 0.5 for $\omega_c \ll K$. Similarly, the optimum value of α ranges from 2.4 for $\omega_c = K$, to K/ω_c for $\omega_c \ll K$. This indicates that for values of ω_c much smaller than K the lead break occurs immediately after the crossover frequency. The values are repeated in the following table:

$\frac{\omega_c}{K}$	1	$\ll 1$
ζ_0	0.7	0.5
α_0	2.4	$\frac{K}{\omega_c}$
F_n	$\frac{\pi}{2}\omega_c$	$\pi\omega_c$

Capture Range: Gruen[5] has shown that the capture range is

$$|\Delta\omega| \simeq \sqrt{2\zeta\omega_n K}, \quad \text{for } \omega_n \ll K \tag{13}$$

or, expressed as a "capture ratio,"

$$\left|\frac{\Delta\omega}{K}\right| = \frac{\text{capture range}}{\text{lock range}} \simeq \sqrt{2\zeta\,\frac{\omega_n}{K}}. \tag{14}$$

Substituting $\zeta_0 = 0.5$ for $\omega_n \ll K$, this ratio becomes

$$\frac{\text{capture range}}{\text{lock range}} \simeq \sqrt{\frac{\omega_n}{K}} \tag{15}$$

for a system with an optimized lag network.

For a system with a simple RC filter ($t_2 = 0$),

$$\zeta = \frac{1}{2}\,\frac{\omega_n}{K}. \tag{16}$$

Substituting (16) in (14) yields

$$\frac{\text{capture range}}{\text{lock range}} \simeq \frac{\omega_n}{K}. \tag{17}$$

Capture Time: Richman[4] states that the capture time depends on the initial frequency offset and the noise bandwidth in the following manner:

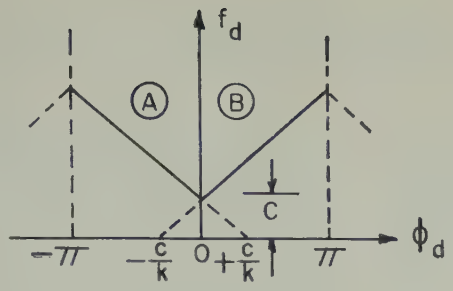

Fig. 6—Composite locking diagram.

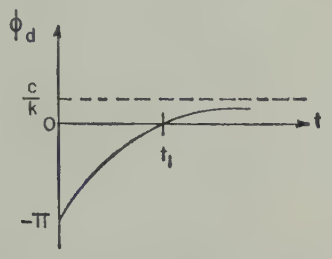

Fig. 7—Phase behavior in Region A.

$$t \simeq 4\frac{\Delta f^2}{F_n{}^3}, \tag{18}$$

except near the limit of the capture range, where the capture time approaches infinity.

Appendix II

Pulling Behavior of an APC Loop

Fig. 6 illustrates what occurs if the rough tuning of the oscillator is such that the range of the phase-detector-reactance-modulator combination is insufficient to allow locking.

In this case,

$f_d = f - f_0$ = instantaneous frequency difference between oscillator and reference.
$\phi_d = \phi - \phi_0$ = instantaneous phase difference.
c = minimum frequency difference allowed by device.
k = slope of f_d vs ϕ_d characteristic.

Initial Conditions: Assume that at $t=0$, $\phi_d = -\pi$, *i.e.*, the operating point starts at the left extremity of Region A.

In Region A:

$$f_d = -k\phi_d + c,$$
$$f_d = (d/dt)\phi_d.$$

Solving:

$$(d/dt)\phi_d = -k\phi_d + c,$$
$$(d/dt)\phi_d + k\phi_d = c,$$
$$\phi_d = (c/k) + Ae^{-kt}.$$

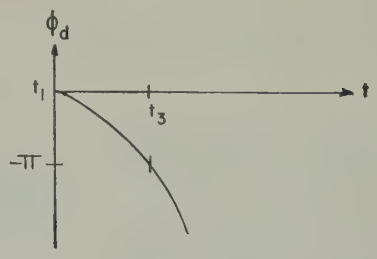

Fig. 8—Phase behavior in Region B.

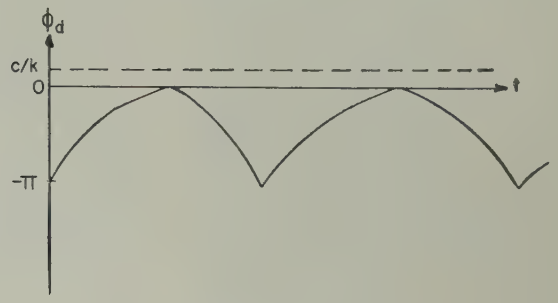

Fig. 9—Steady-state phase behavior.

Substituting initial condition:

$$-\pi = (c/k) + A,$$
$$A = -\pi - (c/k),$$
$$\phi_d = (c/k) - (\pi + c/k)e^{-kt}.$$

The time behavior of ϕ_d is shown in Fig. 7.

However, at $t=t_1$, the operating point enters Region B with initial conditions

$$t = t_1 = t_0'$$
$$\phi_d = 0.$$

In Region B

$$f_d = k\phi_d + c,$$
$$f_d = (d/dt)\phi_d,$$
$$(d/dt)\phi_d = k\phi_d + c,$$
$$(d/dt)\phi_d - k\phi_d = c,$$
$$\phi_d = -(c/k) + Ae^{kt}.$$

Initially,

$$0 = -(c/k) + A,$$
$$A = +(c/k),$$
$$\phi_d = +(c/k)(1 - e^{kt}).$$

The time behavior of ϕ_d is shown in Fig. 8.

However, at t_3, operating point reaches π, re-entering Region A at the proper initial conditions and the process repeats as shown in Fig. 9.

Acknowledgment

The author wishes to express appreciation to M. J. Fitzmorris of the General Radio Company for his assistance in the system analysis.

Correspondence

The Antipodal Reception of Sputnik III*

The permanent recording of satellite signals on 20 mc, carried out at Stanford, Calif., gave some important results. Garriott and Villard, Jr.[1] found that during a period of several weeks, the signal was often detected at a time midway between two direct afternoon passes, while between the morning passes of the same period, practically no antipodal signal was detected. During the next period of about two months no antipodal reception could be noted at all. Practically all detected antipodal signals arrived from the southeast. The authors deduced from the constancy of the Doppler shift and from the direction of arrival that the arriving energy must have been confined to a relatively narrow cone in some unchanging direction. That was in a good agreement with the theoretical conclusions drawn by Woyk.[2-4]

It was inferred[2] that in an ionized layer surrounding the earth there must exist two critical levels along which a radio wave can perpetually propagate. Their somewhat different character is shown in Fig. 1. The

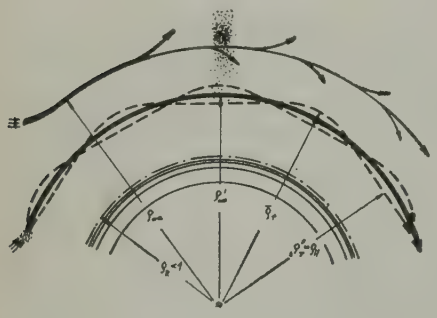

Fig. 1.

propagation along the well-known upper level, ρ_∞, lying close below the maximum of electron density, is rapidly attenuated by a considerable spread of the ray pencil. On the other hand, the new kind of around-the-earth propagation along the lower critical level ρ_∞' is so stable that any ray—once horizontal at this level—can never leave that level as long as the ionosphere remains perfectly spherical. The curvature of the ray there is so small that it equals the curvature of the earth. Even rays which are not quite horizontal at the lower critical level are forced to propagate along it in small pulsations as in a waveguide while they are trapped between two reflecting levels $\bar{\rho}_r$ and $''\rho_r''$ shown in Fig. 1. (The greater electron density above the lower critical level ρ_∞' curves the ray more than at ρ_∞'. Consequently the ray must return to ρ_∞'. Similarly the region below ρ_∞' deviates the ray back to ρ_∞', as below ρ_∞' there are practically no more electrons. Thus the ray is almost rectilinear.) In order to bring the signal from the satellite at this critical level, and then to the earth's surface, there must exist at least two regions in which levels marked by the same electron density are not concentric to the earth's surface. Then, according to the horizontal variation of electron density, both reflecting levels $\bar{\rho}_r$ and $''s_r''$ drift more or less away from each other.[2,4] (The around-the-earth propagation is destroyed when the upper reflecting level s_r has withdrawn beyond the maximum of electron density; in this case, the signal escapes. On the other hand, when the lower reflecting level $''\rho_r''$ has withdrawn below the earth's surface, the signal can be received. For $f \geq 3f^c$, the ray usually escapes before having attained the earth.)

Let us next follow the best conditions for antipodal receptions.

The probability of reception grows rapidly[3] when the satellite approaches the antipodal point. In this singular case, the transmission can occur with the same probability over all possible great circle paths. The preferred direction of arrival, however, depends first of all upon the ionospherical conditions at the points where the ray first touches the ionosphere and where it leaves it, respectively.[4] The first point depends upon the altitude of the satellite, the second is usually about 2000 km from the observer.

Conditions at the Satellite Side of the Ray Path

From the point where the ray first enters below the ionosphere, the critical frequency of the layer must increase. That is necessary because the most horizontal part of the ray pencil which has just penetrated through the ionosphere must be prevented from escaping at the next touch with it (occurring from downwards).

Ionospherical Conditions at the Observer's Side of the Ray Path

At middle latitudes a signal on 20 mc can usually reach the earth's surface only when the levels containing the same electron density are more curved than the earth's surface. Then also the reflecting level is somewhat bent down so that the signal path goes to be more deviated to the earth. Such suitable conditions occur for example when the ray enters into a region where the F layer just splits into two parts or where both parts F_1 and F_2 still withdraw from each other.

From what has been said, no antipodal reception is probable in the direction from polar regions as in the rare polar ionosphere, the ray would have escaped before having reached middle latitudes. On the other hand, its arrival precisely from the south would presume either a transversal variation in electron density having deviated the ray from the great circle path or a high altitude of the satellite so that the most horizontal rays could enter below the ionosphere just near the rarest part of the polar regions.

Considering the conditions at the observer's side, two directions of arrival seem to be preferred: from the southwest in the forenoon and from the southeast in the afternoon. In both these cases the ray enters into a region where the F layer grows thicker. The forenoon passes from the southwest, however, will not be frequent as the ray must have passed the region where the critical frequency falls to its morning minimum, which is deep even in the equatorial zone. It is improbable that the ray would not escape there. When passing through the sunset zone the ray can be split by the turbulence or convective streams so that a multipath propagation can never be excluded; but the antipodal reception need not be destroyed by the sunset region.

According to the elimination just made, we have to expect that at Stanford the best conditions for a frequent antipodal reception occur from the southeast during Summer afternoons. They are likely to be suitable—but less frequent—from the southeast during Winter noons.

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* Received by the IRE, March 30, 1959.

[1] O. K. Garriott and O. G. Villard, Jr., "Antipodal reception of Sputnik III," Proc. IRE, vol. 46, p. 1950; December, 1958.

[2] E. Woyk (Chvojková), "Über den Weltumlauf der Radiostrahlen," *Bull. Astro. Czech.*, vol. 5, pp. 104, 110; November, 1954. And, "The refraction of radio waves by a spherical ionized layer," *J. Atmos. Terrest. Phys.*, in press.

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Apparent Correlation Between Tropopause Height and Long-Distance Transmission Loss at 490 mc*

A short-term experiment has been carried out in central Ontario to examine 490-mc transmissions over a 640-mile path. UHF transmissions over shorter distances have been studied widely during the past fifteen years, and although the physical process which is responsible for them is not fully understood, it is believed generally that the radio signal from the transmitter is scattered or reflected within the troposphere to ranges well beyond the optical horizon. The region in which this scattering or reflection occurs is assumed to be in the common

* Received by the IRE, February 16, 1959.

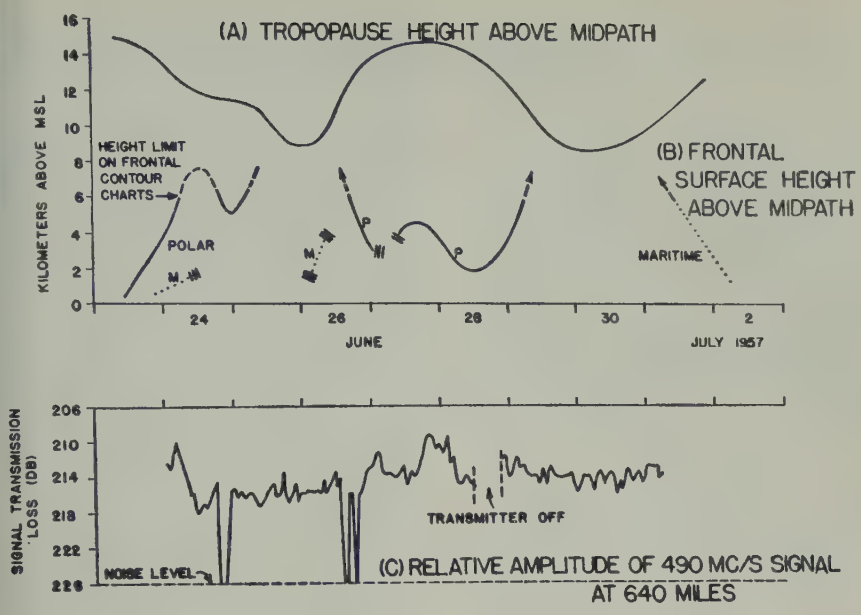

Fig. 1—Measured signal transmission and estimated tropopause height, for the 640-mile path.

volume of the troposphere, which lies above the transmitter and receiver horizons. The question now arises as to what happens to the UHF signal transmission when the receiver is so far from the transmitter that the common volume above the horizon planes lies above the troposphere, within the stratosphere. This is the case when the transmitter and receiver are more than 450 miles apart, the antennas are directed horizontally, and the antenna heights are approximately fifty feet.

It has been established recently that VHF and UHF signals can be transmitted over distances well beyond 450 miles.[1,2] These signals fluctuate in amplitude in a manner not unlike signals transmitted over ranges less than 450 miles. At least three theories have been proposed to explain the physical process of very long range UHF transmission,[3–6] but experimental information to test these theories adequately is lacking.

The experimental radio path in central Ontario was located between Ottawa and Port Arthur. A 10-kw signal was transmitted between 28-foot paraboloidal antennas, and the amplitude of the received signal was recorded continuously for a period of seven days, in June, 1957. Line (C) Fig. 1 illustrates the fluctuations in hourly median transmission loss over the 640-mile path. It will be seen that three brief intervals occurred when the signal was below the noise level of the receiver. Outside of these intervals, the hourly median signal was at least 10 db above the receiver noise level. Closer examination indicates that the seven-day period may be divided into four sections according to the type of fluctuation in signal amplitude, although the total range of fluctuation was only about 8 db. There were two intervals when the signal was relatively weak and fluctuations were limited to 2 or 3 db (June 24th P.M. to June 26th A.M., and June 28th P.M. to July 1st A.M.), and two intervals when the signal was relatively strong and fluctuations were deeper (June 24th A.M., and June 26th P.M. to June 28th A.M.).

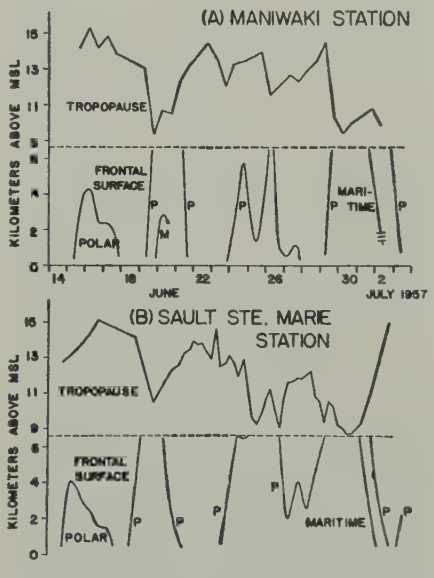

Fig. 2—Tropopause and frontal surface heights at radiosonde stations near the Ottawa-Port Arthur path.

The change in height of the tropopause above the radio path during this seven-day period showed an interesting correlation with signal transmission loss. Recently, it has been established that the height-variation of the tropopause follows a regular pattern in the vicinity of a weather front.[7,8] The tropopause height is greater on the warm-air side of the frontal junction than on the cool-air side. Fig. 2 illustrates this relationship as observed above Maniwaki (near the Ottawa end of the radio path) and above Sault Ste. Marie (near the center of the radio path). Here the minimum tropopause height was 9 km at the cool-air side of the tropopause-frontal junction, and the maximum height was 15 km above the warm air mass. The tropopause height above the center of the Ottawa-Port Arthur path was estimated from this information and from the known frontal positions above mid-path, as shown in (A) and (B) of Fig. 1. A comparison of tropopause height in (A) with the four sections of signal transmission loss plotted in (C) (Fig. 1) indicates that the periods of relatively stable transmission and higher loss were concurrent with a low tropopause, and periods of relatively unstable transmission and lower loss occurred when the tropopause was high. It should be added that a similar analysis of 490-mc transmissions over a distance of 380 miles along the same path failed to show this correlation between signal transmission loss and tropopause height above mid-path. The brief intervals of signal fadeout do not appear to be correlated with frontal position or tropopause height.

It is of further interest to compare the average signal-transmission loss as measured between Ottawa and Port Arthur with that reported from the eastern U.S.A. During the one-week interval, the loss over the 640 mile path between Ottawa and Port Arthur was 125 db greater than the free space loss. On a 618 mile path in the eastern U.S.A., the mean loss during the month of January was only 4 db less than this, for a signal frequency of 413 mc.[2] This transmission loss is some 20 db greater than Bullington's average transmission-loss curves indicate it should be for a 640 mile path.[9]

Further details on this experiment are given in a DRTE Project Report.[10] This work was carried out under Defense Research Board project PCC D48-28-01-03, at the Defence Research Telecommunications Establishment.

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[5] H. G. Booker and W. E. Gordon, "The role of stratospheric scattering in radio communication," Proc. IRE, vol. 45, pp. 1223–1227; September, 1957.
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[8] B. W. Boville, W. S. Creswick, and J. J. Gillis, "A frontal-jet stream cross-section," *Tellus*, vol. 7, pp. 314–321; August, 1955.
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Backward-Wave Oscillations in an Unloaded Waveguide*

A number of investigators have indicated the possibility of obtaining interaction of a low-energy electron beam with an unloaded circuit by having the electrons traverse a periodic trajectory.[1-3] In this manner the slow-wave structure may be eliminated. Particularly if one is interested in short wavelengths, a slow-wave device has the disadvantages of a fabrication problem, matching difficulties, and the decrease of field strength away from the surface of the structure.

Consider, for example, an electron beam traversing a helical path in a dc longitudinal magnetic field, B, as illustrated in Fig. 1. Fig. 2 shows a transverse section of the guide and indicates how interaction may occur with the TE_{11} mode. The magnetic field is adjusted so that the cyclotron frequency is approximately equal to the RF frequency. This means that if an electron is retarded by the field is shown in Fig. 2(a), it will again be retarded by the field upon having rotated π radians as in Fig. 2(b). In this manner a synchronism condition is maintained. In addition to having synchronism, it is also necessary that electrons which are in a phase position to be accelerated do not absorb as much energy as the retarded electrons deliver. A detailed small-signal analysis of this device indicates that the RF fields perturb the electron position in a manner that is appropriate for satisfying this condition.

If the longitudinal motion of the beam is included, then the synchronism condition is slightly altered as in (1).

$$\omega = \frac{\dot{\phi}_0}{1 \pm (\dot{z}_0/v_p)}, \qquad (1)$$

where

$\dot{\phi}_0$ = dc angular velocity (cyclotron frequency),
ω = rf frequency in radians per second,
$\dot{z}_0$ = longitudinal dc velocity,
v_p = phase velocity for the TE_{11} mode.

The plus sign in (1) is applicable if the waveguide mode is propagating opposite to the beam motion, and the minus applies when the mode and beam are propagating in the same direction.

An appropriate ω-β diagram is illustrated in Fig 3. The solid line in Fig. 3 is the usual dispersion curve for an unloaded waveguide. The dashed lines are obtained by letting $\phi = (\dot{\phi}_0/\dot{z}_0)z$, which expresses the dc relationship between angular and longitudinal motion. Thus, an effective propagation constant of the form $(\pm p\dot{\phi}_0/\dot{z}_0 \pm \beta)$ results, where

$\beta = \omega/v_p$
p = an integer corresponding to the number of angular variations of the RF field.

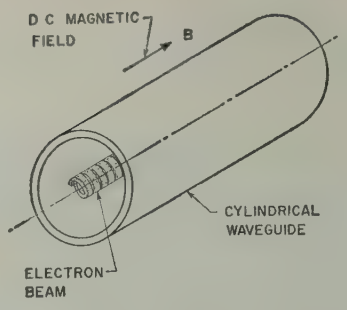

Fig. 1—The beam traverses a helical path in a dc longitudinal magnetic field and interacts with a transverse electric mode in the waveguide.

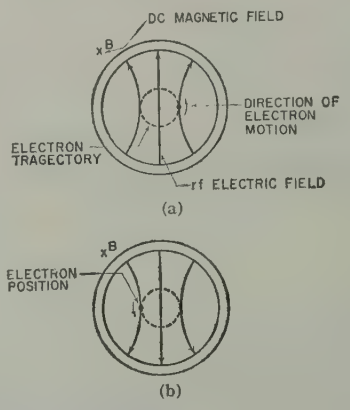

Fig. 2—Synchronism between an electron beam and the dominant waveguide mode may be obtained by having the cyclotron frequency approximately equal to the RF frequency.

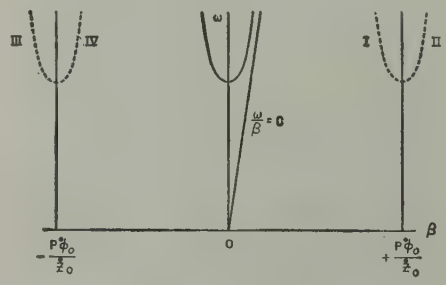

Fig. 3—Dispersion curves for the wave-guide mode along a helical trajectory.

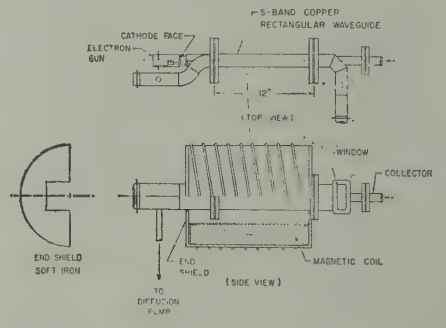

Fig. 4—Experimental setup for obtaining backward-wave oscillations in an unloaded waveguide.

For a TE_{11} mode, $p = 1$. Curve I corresponds to a field propagating in the negative z and positive ϕ directions; curve II corresponds to a field propagating in the positive z and positive ϕ directions; curves III and IV are fields propagating in the negative ϕ and negative and positive z directions respectively.

The apparatus illustrated in Fig. 4 was used to obtain experimental evidence for the generation of backward-wave oscillations in an unloaded waveguide. A shielded cathode emits a solid electron beam which then enters a magnetic field several times the Brillouin field. Under these conditions the electrons rotate at half the cyclotron frequency about the center line of the cathode, and at the cyclotron frequency about their axis of rotation. The tube is standard S-band rectangular waveguide which is matched at the collector end and oscillation power measured at the cathode end. Gun perveance is about 3×10^{-6} and the electron beam is accelerated through 1000 volts. The solenoid is 14 inches between end plates. By varying the magnetic field, oscillations were observed from 2.5 to 4.0 kmc at a power level of 0.4 watt and an efficiency of 0.5 per cent. Starting current varied between 80 and 125 ma.

It should be noted that this novel tube has an order of magnitude increase in transverse linear dimensions as compared to a slow-wave device for a comparable beam voltage. In addition, the strongest fields are in the region of the beam and the matching problem is essentially eliminated.

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The Use of Resolvers*

Resolvers are customarily used for transforming vector coordinates with the use of auxiliary servomechanism. Not generally known is the fact that the resolver itself is quite capable of converting the rectangular components of a vector into polar representation without the benefit of any secondary instrumentation.

If the amplitudes of the carrier waves applied to the stator windings of a resolver are modulated by the rectangular components of an input vector, a stationary field will be set up at an angle equal to the vector phase θ, with respect to the stator. There will also be induced voltages in the two rotor windings. Let one of these rotor windings be open-circuited and the other, at an angle ϕ with respect to the stator, be short-circuited. The resultant short-circuit current produces a torque which is proportional to $\sin^2(\theta - \phi)$ and will set the rotor in motion until it comes to rest at $\phi = \theta$ or $\theta - 180°$, depending on which has the smaller angular displacement from the original position of the rotor. With the rotor at its equilibrium position, induced voltage in the short-circuited rotor winding is zero, while that in the open-circuited one has amplitude equal to the magnitude of the input vector. If rotor angle is at $\phi = \theta$, the output voltage is in phase with the

* Received by the IRE, February 16, 1959.

* Received by the IRE, February 16, 1959. The research reported in this document was supported by National Science Foundation Grant No. G-6316.

[1] H. Kleinwachter, "Excitation of electromagnetic fields by current waves," *Arch. für Eleckt. Über.*, vol. 6, pp. 376–378; September, 1952.

[2] R. Muller, "Space harmonics in electron beams," *Arch. für. Elekt. Über.*, vol. 10, pp. 505–511; December, 1956.

[3] E. J. Gorn, "Traveling-Wave Electron Reaction Device," U. S. Patent 2,591,350; April 1, 1952.

ator input carrier waves. If $\phi=\theta-180°$, he output is out of phase with the stator in- ut by 180°.

In many applications, the input vector oes not have phase discontinuity, or phase ump. The resolver will then be an extremely seful indicating and control device of phase nd magnitude, with the phase of the rotor utput always available for checking possi- le error of 180°. The self-actuating resolver escribed here does not have transformation ccuracy attainable with a servo-driven esolver. But then simplicity alone justifies he use of a short wire in place of even the ost rudimentary servo equipment in any instances.

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International Conference on Radio Wave Propagation*

Approximately 100 radio scientists from 12 countries attended the Congres International sur la Propagation des Ondes Radio-Electriques held on October 6–11, 1958, in the Palais des Congres at Liege, Belgium. The conference was organized by the Postal and Telecommunication Groups of the Universal and International Exposition at Brussels, 1958. A total of 55 papers were presented at the Congres. About half of these papers were from the United States; the rest came from the European countries. Only three papers came from delegates of the Soviet block countries, two from East Germany, and one from Czechoslovakia. None of the five delegates from the USSR presented any papers or participated in the discussions.

The papers presented at the Congres dealt largely with summaries of the work of several years rather than with discrete details. Major discussions concentrated on the following subjects:

1) Distant (beyond-the-horizon) propagation of ultra short radio waves and the application to radio communications.

2) Ionospheric investigations—particularly those using back-scatter sounding techniques.

3) Forward scattering of radio waves from the ionized trails of meteors.

4) Propagation of low-frequency radio waves.

Several of the papers which I considered most significant are summarized in the following pages. Summaries of all the papers are given in the "Resume des Communications" distributed to those who attended the conference. The complete texts of the papers presented at the conference will be published as a special volume by the Academic Press, Inc., New York, N. Y.

* Received by the IRE, February 16, 1959.

Principal European contributions to the discussions of distant (beyond-the-horizon) propagation of ultra short radio waves came from Great Britain, Sweden, France, and Germany.

G. C. Rider, of Marconi's Research Laboratory, Great Baddow, England, described propagation measurements made during 1956–1958 at $f=858$ mc over ranges up to 585 km. He found a positive correlation between signal fading rate and wind velocity and negative correlation between signal strength and wind velocity. He also found that when a polar air mass was over the propagation path the signal strength was low. Rider showed plots of the hourly median values of signal strength vs path length (actually given in terms of the angle subtended by the path at the center of the earth).

G. Carlson, of the Research Institute of National Defense, Stockholm, Sweden, described experiments with pulsed signals at $f=3000$ mc over a distance of 300 km in the middle of Sweden. He found that the median signal was 83 db below the free-space level and that the fading range between the 10 per cent and 90 per cent levels was about 11 db.

F. du Castel and P. Misme, of the Centre National d'Etudes des Telecommunications, Paris, France, discussed the results of many months of measurements in French Equatorial Africa on the propagation of radio waves at $f=432$ mc over ranges of 170–280 km. They mentioned the difficulty of interpreting their experimental measurements on the basis of turbulent diffusion. They were examining the importance of reflection from layers in the troposphere and from this point of view had obtained theoretical values of the field strengths at great distance which seemed in accord with the principal experimental data.

U. Kuhn, of the Betreibslaboratorium für Rundfunk und Fernsehen, discussed the propagation of VHF and UHF radio waves over irregular terrain. He presented plots showing the dependence of local field strength variations on terrain irregularities for different frequency regions. In essence he investigated the discrepancies between the practical field strength measurements and the theoretical field strength values for the smooth earth.

L. Ames, of the U. S. Air Force Cambridge Research Center, discussed airborne measurements of radio fields of a transmitter operating at $\lambda=1.36$ m out to ranges exceeding 900 miles and altitudes exceeding 40,000 feet. Representatives of the U. S. Air Force Cambridge Research Center and Rome Air Development Center discussed applications of the troposphere scatter mode of propagation to USAF communications.

Principal papers by the Europeans on radio propagation experiments involving the ionosphere came from the representatives from Italy and Germany.

I. Ranzi, of Centro Radioelettrico Sperimentale (G. Marconi), Rome, Italy, described experiments being performed near Rome on oblique back-scatter soundings using a rotating Yagi antenna. He compared skip distances observed by back scatter with skip distances deduced from vertical sounding near the midpoint of the path and found discrepancies.

W. Dieminger, of the Max Planck Institut für Aeronomie, Lindau über Northeim, Germany, reported on combined vertical soundings of the ionosphere, oblique incidence propagation, and back-scatter experiments which were carried out over distances of 2000 km and 8000 km. In particular he discussed the difference between the values of the MUF (maximum usable frequency) derived from the vertical soundings and the values observed in the simultaneous oblique incidence propagation experiments. He also indicated agreement between the oblique incidence propagation experiments and simultaneous back-scatter measurements. Dieminger apparently uses two methods for his back-scatter experiments. In the first method he uses a fixed frequency rotating antenna and obtains the zone of reception as a function of the bearing of the antenna beam. In the second method he has the antenna on a fixed bearing and varies the frequency of his back-scatter radar, thus obtaining the extent of the skip zone as a function of frequency.

B. Beckmann and K. Vogt, of Fernmeldetechnisches Zentralamt, Darmstadt, Germany, reported on back-scatter observations with telegraphy signals. They described a simple procedure depending on back-scatter amplitude observation that is suitable for an evaluation of ionosphere communication conditions. The scheme has been developed by the German post office for application to telegraphic communications. Since with telegraph signals the travel time of the back scatter is small compared with duration of the signal, the back-scatter amplitude affects the envelope of the telegraph signal as observed in the intermediate frequency channel of the receiver. One observes amplitude discontinuities which can best be observed by the "ring method" of display in which the IF voltage of the receiver is applied to one pair of plates of an oscilloscope and the same IF voltage shifted in phase 90° is applied to the orthogonal pair of plates. One then assesses the ionosphere communication conditions from observing on the scope the first discontinuity caused by the back-scatter amplitude. Observations show that the amplitude of the back scatter increases as the size of the skip zone decreases and as the ionosphere attenuation decreases. Since both of these factors determine the propagation conditions, the actual usable communication frequency of the ionosphere can be estimated at the transmitter location. Back-scatter observations taken simultaneously with short pulses and with longer telegraph signals were compared. Finally back-scatter measurements at $f=25.4$ mc with directive antennas in the direction of North America were compared with a field strength record of the American transmitter WWV at $f=25$ mc.

Papers dealing with the forward scattering of radio waves from the ionized trails of meteors were given by representatives from Great Britain and the United States.

G. A. Isted, of Marconi's Research Laboratories, Great Baddow, England, discussed meteor activity as a factor in ionosphere scatter propagation. Although ionosphere

scatter links have been operating now for several years, the observed propagation effects have not all been satisfactorily explained. Ionization by meteors undoubtedly contributes to ionospheric forward scattering. Isted suggests that weather cloud discharges may be capable of producing bursts of ionization similar to those produced by meteors. He has found groups of bursts and thundercloud discharges associated with these burst groups.

J. S. Greenhow and E. L. Neufeld, of the Joddrell Bank Experimental Station, University of Manchester, England, discussed turbulence in the lower E region of the ionosphere as inferred from meteor echo observations. Under the influence of high altitude winds the ionized trails of meteors show steady drifts due to uniform wind motions and become distorted through the effects of turbulence. Using a single station coherent pulse technique the authors have measured the steady winds and have found a prevailing component and regular 12-hour and 24-hour periodic variations. Using a spaced station coherent pulse technique with two receivers spaced at different distances from the transmitter they can make simultaneous wind velocity measurements at two points along a single meteor trail. From measurements on many trails they infer the wind shears over different heights. The median value of wind shear is found to be 10 m/sec /km with occasional observed values of 100 m/sec/km. The turbulent velocity is about 25 m/sec.

T. J. Keary and H. J. Wirth, of the U. S. Navy Electronics Laboratory, San Diego, Calif., discussed the statistical characteristics of forward-scattered echoes from meteor trails as determined from experimental observations made over a 690 km path from Stanford, Calif., to San Diego, Calif. at $f=43.5$ mc.

J. Heritage, S. Weisbrod, and W. Fay, of Smyth Research Associates, San Diego, Calif., reported (paper communicated by L. Trolese) on an experimental study of meteor echoes at $f=200$ mc with the receiving sites at distances of 800, 1300, 1800 km from the transmitter. The transmission path was oriented SE–NW. The shapes of the echoes observed at $f=200$ mc are found to be extremely varied. The rates of occurrence of echoes showed the usual diurnal variation with highest rates in the morning hours. A comparison was made between rates of occurrence observed at receiving sites located NE of great circle path defined by the sharp transmitter beam with those located SW of it. In general the rates of occurrence were higher at the SW sites during the hours 0700 to 1700 and higher at the NE sites during 1700 to 0700.

Aspects of the propagation of low frequency radio waves were discussed principally by representatives of the United States and Germany.

J. R. Wait, of the National Bureau of Standards, Boulder, Colo., reviewed theoretical approaches to the understanding of the propagation of long radio waves over the surface of the earth. The two principal lines of approach are the mode theory and the ray theory. At frequencies $f>20$ kc and at long ranges the mode theory is cumbersome to apply as many modes must be taken into account in computing the mode series to give the field. Hence it is usual to calculate distant fields by the geometrical optics or ray methods. Wait compared his calculated results with experimental data at $f=16.6$ kc taken by members of the U. S. Navy Electronics Laboratory.

B. Friedman, of the University of California, Berkeley, Calif., discussed from the standpoint of mode theory the field produced by a low frequency vertical electric dipole located between a perfectly conducting earth and an ionosphere assumed to have a sharp lower boundary. He discussed the attenuation of the individual modes.

E. A. Lauter, of the Observatorium für Ionosphären Forschung, Ostseebad, Kuhlingsborn, reported on measurements taken over a period of 10 years on the reflection coefficients of the ionosphere at a frequency $f=245$ kc. He finds that for the undisturbed ionosphere the variation of reflection coefficients can be described by a log-normal distribution. During earth magnetic storms there are strong departures from the normal distribution.

K. Rawer, of the Fernmeldetechnisches Zentralamt, Aussenstelle Ionosphären-Institut, Breisach/Rhein, compared different methods of calculating the field strengths of radio waves reflected from the ionosphere.

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A Topological Nonreciprocal Network Element*

In order to extend equivalent circuit representation to nonreciprocal networks it has been found necessary to augment the set of ideal elements required for reciprocal networks (*viz.*, the independent two-terminal generator, the two-terminal immittance and the ideal transformer) by an essentially two-terminal-pair (two-port) nonreciprocal element. A variety of elements,[1–7] of which the gyrator appears to have gained the widest acceptance, has been proposed for this purpose. These elements are generally characterized by physical (transfer immittance) as well as topological (connective) properties. It is the intention of this communication to indicate that the physical and topological properties may be segregated and the latter accounted for by an element which, in association with physical elements (immittances) may be used to model the more complex nonreciprocal elements so far proposed.

The proposed element is shown in Fig. 1(a); it is an irreducible essentially transmissive three-terminal device 123 which provides unit gain unilateral voltage transmis-v sion over path 132 (*i.e.*, from 13 to 32, with 3 common), unit gain unilateral current transmission over path 213 and null transmission over the four remaining paths. Its transmission matrices for paths 132, 213 have unity in the 11, or 22 element positions, with zeros elsewhere. When a signal potential is established at terminal 1 it is transmitted unilaterally, without change, to terminal 2. Dually, when a signal current is set up in the lead to terminal 2 it is transmitted unilaterally, without change (except, under the usual symmetrical sign convention, for reversal of sign) to terminal 3. There must, of course, be a continuous external current path between 23, one point of which will normally form a node-pair with terminal 1 and will form the reference or ground node. The union of these elements with the 123 element comprises a topological space, into which physical, *i.e.*, generative, storage and dissipative, elements may be introduced. It may be shown that the two unit-gain transmission processes are not separable, but that the one necessarily implies the other; they are dual aspects of a single common transfer mechanism, or transfer action (transaction). They are indicated in Fig. 1(a) by directive equality signs, using open arrowheads for voltage transmission, closed heads for current. The signal flow properties are shown graphically in Fig. 1(b), where the available terminal-pairs 12, 23, 31 are connected by directed line segments which are also distinguished by open or closed arrowheads and are labelled with the terminal sequence 132, 213 in the corresponding transmission path.

The two transmission paths may be cascade-coupled in either of two distinct ways. When an immittance Y is inserted in the lead to terminal 2, between 2 and the ground node 0 [see Fig. 2(a)], it acts as a voltage-to-current convertor and defines $i2$ at $i2=-Y\cdot v2=-Y\cdot v1$ and, hence, $i3$ at $i3=Y\cdot v1$. The over-all result is a unilateral coupling between the node-pair 10 and the branch 30 over path 132 through the nonreciprocal 123 element, which is equivalent to a direct unilateral transadmittance action (admittance transaction), as shown by the signal flow graph at Fig. 2(b). Dually, when an immittance Z is bridged across terminals 1,3 [see Fig. 2(c)] it acts as a current-voltage convertor and couples the two unilateral paths in the opposite sequence, the over-all result being equivalent to a direct unilateral transimpedance action (impedance transaction), as illustrated by the flow graph [Fig. 2(d)]. By cascading a 123 element, appropriately oriented, with an ideal transformer of nonunit ratio, unilateral current-current or voltage-voltage transactions of other than unity ratio may be obtained. Thus, all four of the set of transactors introduced by the

* Received by the IRE, February 18, 1959.

[1] B. D. H. Tellegen, "The gyrator, a new electric network element," *Philips Res. Rept.*, vol. 3, pp. 81–101; April, 1958.

[2] J. Shekel, "The gyrator as a 3-terminal element," PROC. IRE, vol. 41, pp. 1014–1016; August, 1953 and "Reciprocity relations in active 3-terminal elements," *ibid.*, vol. 42, pp. 1268–1270; August, 1954.

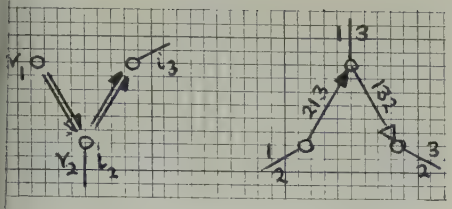
[3] W. S. Percival, "The graphs of active networks," *Proc. IEE*, vol. 102, pt. C, pp. 270–278; September, 1955.

[4] S. J. Mason, "Docile behavior of feedback amplifiers," PROC. IRE, vol. 44, pp. 781–787; June, 1956 and "Topological analysis of linear nonreciprocal networks," *ibid.*, vol. 45, pp. 829–838; June, 1957.

[5] J. L. Merrill, "Theory of the negative impedance converter," *Bell Sys. Tech. J.*, vol. 30, pp. 88–109; January, 1951.

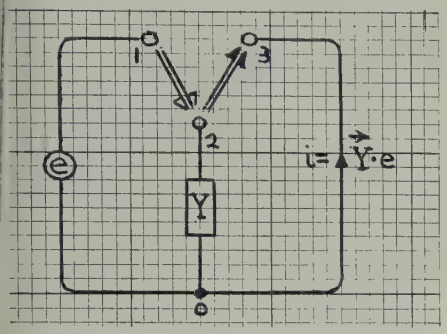
[6] E. F. Bolinder, "Survey of some properties of linear networks," IRE TRANS. ON CIRCUIT THEORY, vol. CT-4, pp. 70–78; September, 1957.

[7] G. E. Sharpe, "Axioms on transactors," IRE TRANS. ON CIRCUIT THEORY, vol. CT-5, pp. 189–197; September, 1958.

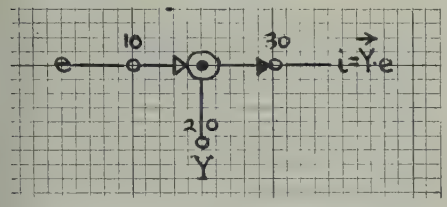


(a) (b)

Fig. 1—(a) The proposed nonreciprocal network element and (b) its signal flow graph.



(a)



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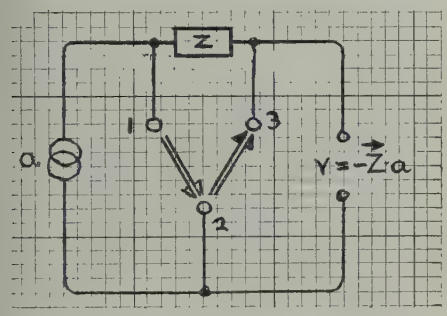

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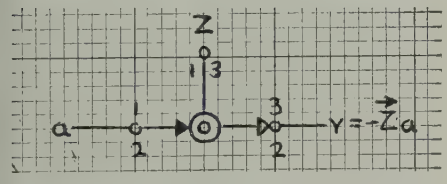
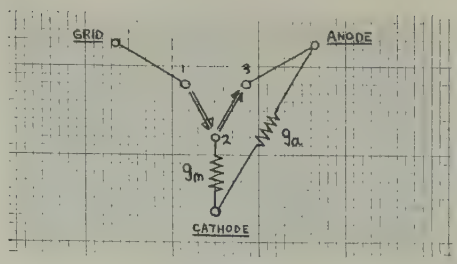


(d)

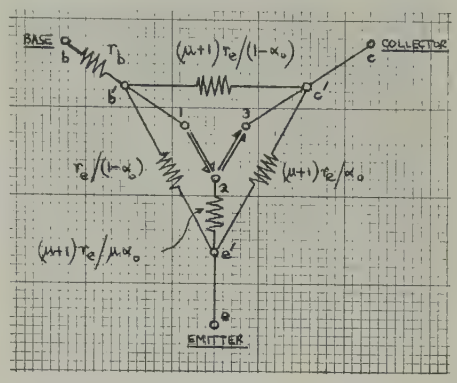
Fig. 2—The dual basic operating circuits of the proposed element: (a) admittance form, (b) flow graph, (c) impedance form and (d) flow graph.

author in a previous communication[8] may be modeled by the one type of nonreciprocal element in association with established reciprocal elements. To obtain complex current or voltage transaction, *i.e.*, unilateral transformation, it is sufficient to connect a unit real immittance across 10 in Fig. 2(a) or in series with the lead to 1 in Fig. 2(c), with Y and Z complex, respectively. Immittances

[8] A. W. Keen, "Transactive network elements," *J.I.E.E.*, vol. 3, pp. 213–214; April, 1957. And, "The transactor," *Elec. and Rad. Eng.*, vol. 34, pp. 459–461; December, 1957.



(a)



(b)

Fig. 3—(a) Models of the linear low-frequency negative-grid thermionic triode and (b) the corresponding transistor.

may be associated with the output side in a similar manner, so that current and voltage amplifiers having any one of the four basic feedback configurations (*viz.* series-series, series-shunt, shunt-series, shunt-shunt) may be formed.

By proceeding in this way one may develop the circuit technique of the 123 element to embrace thermionic tube and transistor circuit technique as particular cases. Models of the small-signal, low-frequency action of the tube and transistor are shown in Fig. 3(a) and 3(b), respectively. In both cases the model consists of a nonreciprocal 123 element imbedded in a reciprocal shell and it will be noted that all of the parameters of the device are assigned to immittances in the latter portion. By successive stripping of the shell immittances, the transistor model reduces in turn to its intrinsic form to the equivalent of a tube, to an admittance transactor and, finally, to the 123 element itself.

An important class of networks arises from closure of the internal transmission path of the 123 element by an external signal-flow path between 3 and 1 with the ground point 0 common. The result is a feedback circuit, the simplest examples of which are the basic thermionic triode circuits.[9] Alternatively, the feedback loop may be formed by a second 123 element coupled to the first in such an orientation that at least three of the four internal transmission paths occur in cascade. Such forms may be used to model any of the proposed bilateral nonreciprocal elements (gyrator, anti-symmetrical amplifier, impedance invertor, etc.). As an example, the series-series feedback form for the gyrator is given in Fig. 4, which

[9] A. W. Keen, "Triode network ropology," IRE Trans. on Circuit Theory (to be published).

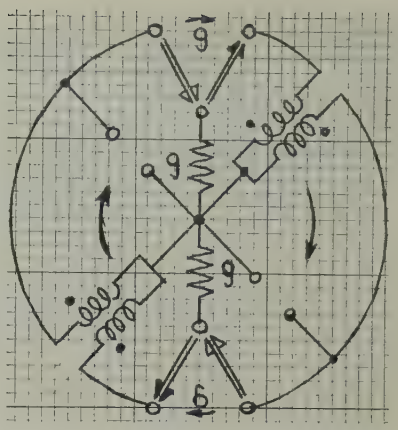
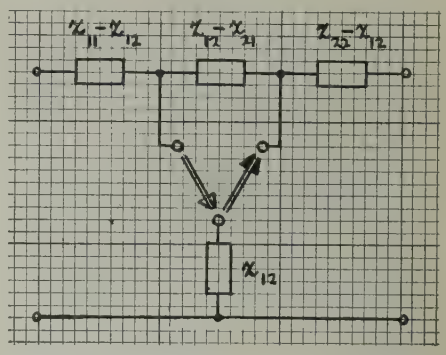
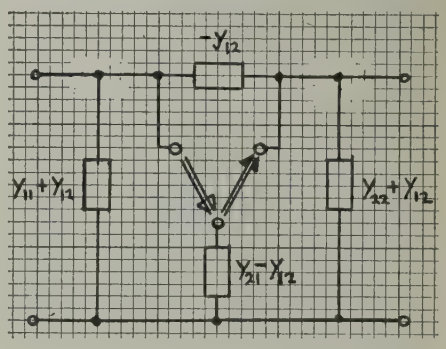


Fig. 4—Model of the admittance form of the gyrator [with g 1 and all three terminal pairs (ports) available for external connection].



(a)



(b)

Fig. 5—Models of the general two-terminal pair network. (a) Impedance form and (b) admittance form.

illustrates very clearly its action. Only one of the two ideal transformers used is necessary, the one which provides inversion and thereby avoids the need for a negative real immittance. In the special case of unit g elements and with all three terminal-pairs brought out for external connection, Fig. 4 becomes a 3-port circulator.[10] The general nonreciprocal two-terminal-pair network may be represented by models containing either one or two 123 elements associated with four distinct immittances in any one of the four feedback configurations, *i.e.*, in forms corresponding to the G, H, Y and Z matrices; the Y and Z forms are shown in Fig. 5(a) and 5(b), respectively.

[10] H. J. Carlin, "Synthesis of nonreciprocal networks" *Polytech. Inst. Bklyn. Symp. Series*, vol. 5, pp. 11–44; April, 1955.

There remains the question of a suitable name for the 123 element. The author has used univactor and univator in unpublished work but would suggest that UNITOR expresses succinctly the essential characteristics, *viz.*, unilateral signal connectivity, unit gain-magnitude and unity of structure.

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X Circulator*

Introduction

Circulators consisting of junction of rectangular waveguides containing a nonreciprocal element—a properly magnetized ferrite—have been proposed and developed by many authors.[1-3]

In this paper I would like to propose mainly a new four-port waveguide circulator of the structure shown in Fig. 1 which is simple in structure, small in volume, light in weight, and pretty good in characteristics. The operation of this device is based on the same principle as the *Y* circulator[2] and the *T* circulator[3] of the three-port structure, although the exact theory of its operation has not yet been analyzed. Next I would like to discuss the experimental results of the proposed circulator in *X* band.

Experimental Results

The ferrite (or garnet) element whose material, shape, and size are proper for the characteristics of a circulator, is inserted with a suitable impedance element at the right place in the usual *H*-type four-port waveguide junction, in which four standard rectangular waveguides in *X* band (WR-90) intersect at right angles at one point. Then a dc external magnetic field is applied to this ferrite element, transverse to the broad side of this waveguide junction by an external electromagnet.

When the wave of 9375-mc frequency enters, for example, through arm 4 from a matched generator, it comes out from arms 1, 2, and 3 terminated by matched detectors. Their transmission losses are shown against the applied dc magnetic field in Fig. 2. When the external dc magnetic field strength *Ho* corresponding to point *A* or *B* in this figure is applied, the counter-clockwise or clockwise circulator is made up, respectively. In practice barium ferrites having about 300 oersteds are set to this junction; the frequency characteristics of the circulator corresponding to point *B* in Fig. 2 are shown in Fig. 3. In the above-mentioned

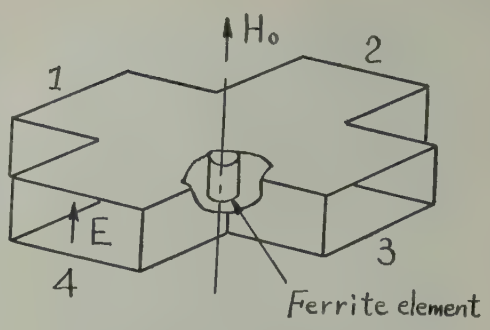

Fig. 1—X circulator.

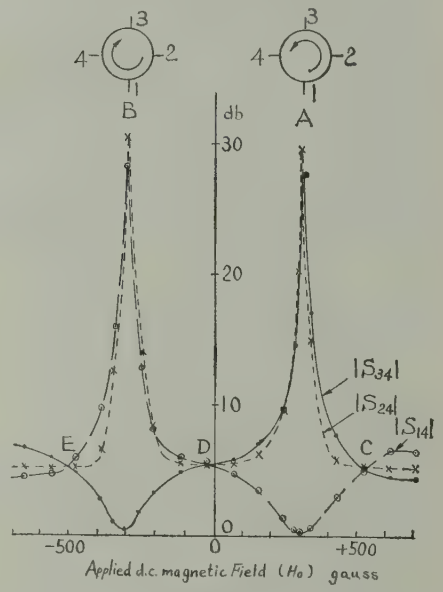

Fig. 2—Transmission loss vs dc magnetic field.

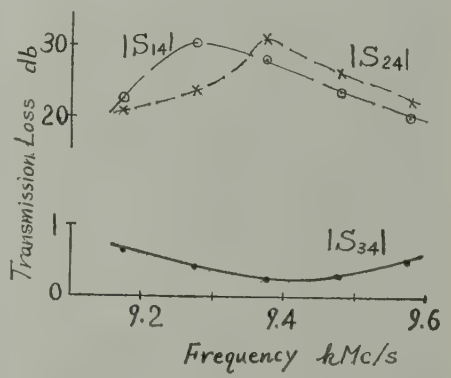

Fig. 3—Transmission loss vs frequency.

example, a rod of manganese magnesium ferrite is placed on the bottom broad wall at the center of the junction as the nonreciprocal element, against the impedance element which is needed to improve the characteristics of the circulator (Fig. 1). When the wave enters from any other arm, the characteristics previously mentioned are kept almost the same.

As the result of the trial to reduce the external dc magnetic field strength proper for the circulator characteristics, the circulator, which needs about 130 oersteds and which has almost the same electrical characteristics, is made by choosing the ferrite element of the same material which is thinner in diameter and bigger in height, with the same kind of the impedance element.

When the external dc magnetic field strength *Ho* corresponding to point *C*, *D*, or *E* in Fig. 2 is applied, the four-port matched equal power divider in the nonreciprocal circuit is made up successfully in practice.

In the case of the four-port *H*-type waveguide junction made of four standard rectangular waveguides in *X* band, two of which intersect at 180°, and three of which intersect at 60°, a circulator is made successfully by using almost the same technique. However, its characteristics are inferior to the *X* circulator at present.

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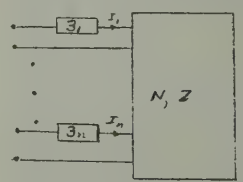
A Stability Characterization of the Reciprocal Linear Passive N Port*

It is well known[1-3] that a reciprocal two-port is passive if and only if it is stable under all passive terminations. Does this theorem generalize to the linear reciprocal *n* port? To the author's best knowledge this question has never been answered. In this note we prove that the answer is in the affirmative.

Let A be an arbitrary matrix. Then A', $\overline{A}$, A^* and det A stand for the transpose, the complex conjugate, the complex conjugate transpose and the determinant of A, respectively. Column vectors are represented by $\boldsymbol{a}$, $\boldsymbol{b}$, $\boldsymbol{x}$, $\boldsymbol{I}$, etc. For a hermetian matrix $A=A^*$, $A\geq 0$ means that A is the matrix of a non-negative form and $A>0$ that it is the matrix of a positive form. A diagonal matrix A with diagonal elements $\mu_1, \mu_2, \cdots, \mu_n$ is written as $A=\text{diag}\,[\mu_1, \mu_2, \cdots, \mu_n]$.

Theorem 1: Let $Z(i\omega)=Z'(j\omega)$ be the impedance matrix of a reciprocal n port N. Then N is strictly passive, *i.e.*, Re $Z(j\omega)>0$, if and only if it is stable.

Proof: Refer to Fig. 1. Suppose Re $Z>0$ and N is not stable. By definition there exist n complex numbers $z_1, z_2, \cdots, z_n$ with non-



$$\underset{\sim}{I}=(I_1, \cdots, I_n)'$$

Fig. 1

* Received by the IRE, January 26, 1959; revised manuscript received, February 19, 1959.

[1] For example, see A. G. Fox, S. E. Miller and M. T. Weiss, *Bell Sys. Tech. J.*, vol. 34, pp. 65–103; January, 1955.

[2] This circulator was investigated by M. H. Sirvetz and his collaborators in Research Div., Raytheon Mfg. Co. last spring.

[3] W. E. Swanson and G. J. Wheeler, "Tee circulator," 1958 WESCON Convention Record, pt. 1, pp. 151–156.

* Received by the IRE, February 10, 1959. The reported herein was sponsored by the Air Force Office of Scientific Research under Contract No. AF-18 (603)–105.

[1] F. B. Llewellyn, "Some fundamental properties of transmission systems," Proc. IRE, vol. 44, pp. 1345–1368; October, 1956.

[2] G. Raisbeck, "A definition of passive linear networks in terms of time and energy," *J. Appl. Phys.*, vol. 25, pp. 1510–1514; December, 1954.

[3] E. Folke Bolinder, "Survey of some properties of linear networks," IRE Trans. on Circuit Theory, vol. CT-4, pp. 70–78; September, 1957.

negative real parts $r_1, r_2, \cdots, r_n$, so that the linear system

$$(Z + Z_0)I = 0,$$
$$Z_0 = \text{diag}\,[z_1, z_2, \cdots, z_n], \qquad (1)$$

possesses a nontrivial solution I. From (1),

$$I^*(\text{Re } Z)I = -\sum_{k=1}^{n} r_k |I_k|^2 \leq 0,$$

a contradiction. Thus stability is necessary.

Sufficiency. For $n=1$ this is obvious. For arbitrary n we proceed by induction, that is to say we assume the result to be true for all $n<k+1$ and show that this implies its truth for $n=k+1$.

By hypothesis the $(k+1)$ port N is stable from which it is easily seen that the k port N_1 [Fig. 2(a)] and 1 port N_2 [Fig. 2(b)] that are created by 1) terminating the $(k+1)$th port of N in an arbitrary passive impedance z and 2) open-circuiting respectively the first k ports of N are also stable. Partition Z as follows:

$$Z = \begin{matrix} \\ k \end{matrix} \overset{\begin{matrix} 1 \end{matrix}}{\left(\begin{array}{c|c} Z_a & Z_b \\ \hline Z_b' & Z_c \end{array}\right)} \begin{matrix} k \\ 1 \end{matrix}. \qquad (2)$$

The impedance matrices of N_1 and N_2 are

$$Z_1 = Z_a - \frac{Z_b Z_b'}{z + Z_c} \qquad (3)$$

and

$$Z_2 = Z_c, \qquad (4)$$

respectively. By the induction hypothesis, Re $Z_1>0$, Re $Z_c>0$. In particular, when $z=\infty$, $Z_1=Z_a$ and therefore Re $Z_a>0$. The object of course is to prove that

$$\text{Re } Z = \left(\begin{array}{c|c} \text{Re } Z_a & \text{Re } Z_b \\ \hline \text{Re } Z_b' & \text{Re } Z_c \end{array}\right) > 0. \qquad (5)$$

Because Re $Z_a>0$, it is only necessary, according to a standard theorem concerning positive forms,[4] to establish that det (Re Z) >0.

Let x be any real k vector. Then

$$\text{Re } x'Z_1x > 0. \qquad (6)$$

Let

$$a = x'Z_ax,$$
$$c = Z_b'x,$$
$$d = Z_c \qquad (7)$$

and

$$W = x'Z_1x.$$

From (3),

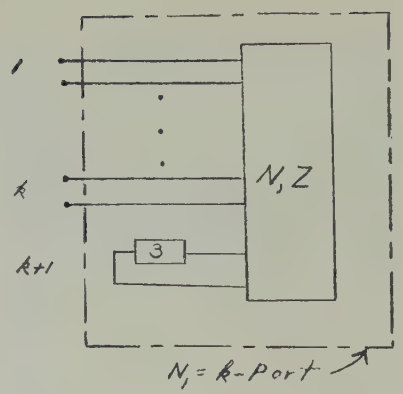
$$W = a - \frac{c^2}{z + d} \qquad (8)$$

and (6) implies that Re $W>0$ for every z having a non-negative real part. In other words W maps the closed right half-plane into the open right half-plane. We leave it to the reader to verify that this is the case if and only if

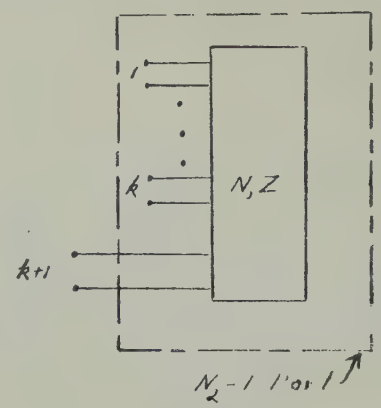
$$(\text{Re } a)(\text{Re } d) - (\text{Re } c)^2 > 0, \qquad (9)$$

or substituting from (7), if and only if

[4] Mirsky, "Introduction to Linear Algebra," Clarendon Press, Oxford, Eng.; 1955.



(a)



(b)

Fig. 2

$$x'[(\text{Re } Z_a)(\text{Re } Z_c) - (\text{Re } Z_b)(\text{Re } Z_b')]x > 0 \qquad (10)$$

for every real k vector x. Hence the real symmetric $k\times k$ matrix

$$V = (\text{Re } Z_c)(\text{Re } Z_a) - (\text{Re } Z_b)(\text{Re } Z_b') \qquad (11)$$

is the matrix of a positive form whence[4] det $V>0$. From the identity

$$\left(\begin{array}{c|c} \text{Re } Z_a & \text{Re } Z_b \\ \hline \text{Re } Z_b' & \text{Re } Z_c \end{array}\right) \cdot \left(\begin{array}{c|c} 1_k \text{ Re } Z_c & 0_{k,1} \\ \hline -\text{Re } Z_b' & 1_1 \end{array}\right) = \left(\begin{array}{c|c} V & \text{Re } Z_b \\ \hline 0_{1,k} & \text{Re } Z_c \end{array}\right) \qquad (12)$$

we get, by taking determinants of both sides,

$$\det (\text{Re } Z) = \frac{\det V}{(\text{Re } Z_c)^{k-1}} > 0. \qquad (13)$$

The proof is now completed by induction from $n=1$, Q.E.D.

The definition of stability we have adopted is the conventional one: an n port N is stable if the port currents are zero under all passive terminations. Evidently lossless networks are not stable. To remedy this defect we introduce the notion of weak stability: an n port N is weakly stable if the port currents are zero under all passive terminations whose real parts are simultaneously positive (zero is excluded). It is now possible to give a stability characterization of all reciprocal passive n ports.

Theorem 2: Let $Z=Z'$ be the impedance matrix of a reciprocal n port N. Then N is passive, *i.e.*, Re $Z\geq 0$, if and only if it is weakly stable.

Proof: For any $\epsilon>0$, $Z+\epsilon 1_n$ is the impedance matrix of a reciprocal stable n port. Invoking Theorem 1,

$$\text{Re } b^*(Z + \epsilon 1_n)b > 0$$

for any nontrivial n vector b. Going to the limit,

$$\text{Re } (b^*Zb) = \lim_{\epsilon \to 0} \text{Re } b^*(Z + \epsilon 1_n)b > 0,$$

i.e., N is passive, Q.E.D.

The author wishes to take this opportunity to thank Dr. Carlin of these Laboratories for suggesting the problem.

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Minimum Transmitter System Weight for Space Communications*

In a space communications link, the required transmitter power is decreased as the transmitter antenna gain is increased, all other parameters remaining constant. Thus, the link may utilize a light-weight, low-power transmitter with a large, high-gain antenna or a heavy-weight, high-power transmitter with a small, low-gain antenna. We wish to call attention to the fact that for a required transmitter-power-antenna-gain product, there exists an optimum transmitter power and antenna gain from the standpoint of minimizing the weight of the total transmitting system.

The weight of the transmitting antenna, W_A, may be given by the relation

$$W_A = CD^2 \qquad (1)$$

where D is the diameter of the antenna aperture, and C is a constant dependent upon the type of antenna used. For a parabolic antenna constructed of alumnized-phenolic honeycomb with a Fibreglass skin one-half inch thick, C equals 0.16 pound per square foot. (This assumes the thickness is independent of the diameter, which, in weightless space, is reasonable for diameters up to 60 ft.)

The transmitter power is taken to be proportional to the transmitter weight, plus the weight of the power source. The total transmitter weight, W_X, is expressed as

$$W_X = (K_X + K_B)P_I \qquad (2)$$

where P_I is the transmitter input power, K_X is the constant relating the transmitter power to its weight, and K_B is the constant relating the battery power to its weight. Present-day transmitters in the 2000-mc range have an estimated K of 1.5 pounds per watt. Solar batteries, illuminated 50 per cent of the time, give an estimated value of 0.2 pound per watt for K_B. This includes any necessary storage batteries.

The communication link requires a certain transmitter-power-antenna-gain product (depending on range, bandwidth, signal-to-noise, etc.) The antenna gain is propor-

* Received by the IRE, March 12, 1959.

tional to the square of its diameter; therefore, the product, M, is expressed as

$$M = P_I D^2 \tag{3}$$

where P_I is the input power to the transmitter (determined by the transmitter efficiency) and D is the antenna diameter.

The total weight of the space vehicle's transmitter-antenna combination is from (1) and (2) and expressed as

$$W = W_A + W_X = CD^2 + (K_X + K_B)P_I. \tag{4}$$

Substituting for P_I from (3) and letting $K = K_X + K_B$,

$$W = CD^2 + \frac{KM}{D^2}. \tag{5}$$

By differentiating (5) we find the antenna diameter which leads to the minimum total weight and expressed as

$$D = \left[\frac{KM}{C}\right]^{1/4}. \tag{6}$$

The optimum transmitter power then is determined from (3).

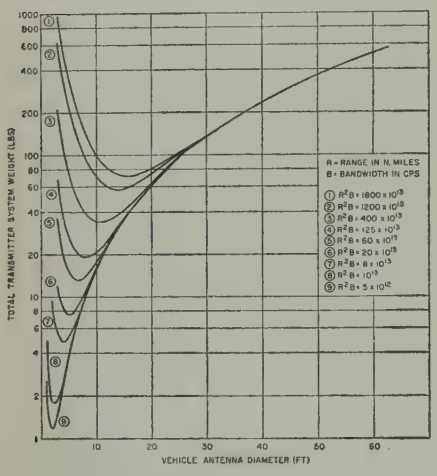

Fig. 1—Total weight vs transmitting antenna diameter with 60-ft receiving antenna at 2000 mc.

Fig. 1 shows a plot of total weights versus antenna diameters. With a frequency of 2000 mc, the assumed parameters were

$C = 0.147$ pound per square foot
$K_X = 1.5$ pounds per watt
$K_B = 0.2$ pound per watt
$K = 1.7$ pounds per watt

$$M \triangleq \frac{(C/N)16k(FT)R^2B\alpha(6080)^2}{E_f G_r \eta}$$

$\frac{C}{N}$ = carrier-to-noise ratio = 30 db
FT = receiver sensitivity = 30° K
α = system losses = 10 db
$k = 1.4 \times 10^{-23}$ joules/°K
R = range in nautical miles
B = bandwidth in cps
E_f = over-all transmitter efficiency = 0.2
G_r = receiving antenna gain = 79,400
η = efficiency of transmitting antenna aperture = 0.55.

One can see how the optimum diameter varies with the range; therefore, an actual design would be based on the maximum range expected. Other considerations, such as limitations on the transmitter antenna pointing accuracy, could alter the design criteria described above.

The authors wish to thank Walter Kanytsky of the Philco Western Development Laboratories' Advanced Development Group for deriving and plotting Fig. 1.

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Fig. 1—University of Illinois moon beam antenna.

A Log-Periodic Reflector Feed*

A need for rapidly changing the operating frequency of the University of Illinois "moon bounce" receiving antenna, pictured in Fig. 1, resulted in the installation of the log-periodic primary feed, shown in Fig. 2. The twenty-eight-foot-diameter dish was originally fed with a corner reflector at 150 mc and a sectoral horn at 415 mc. Approximately a day was required in the necessary interchange of feeds when switching from one band to the other. The need for reducing this time to something comparable to that of changing receivers arose when it was decided that measurements at two widely separated frequencies at the same, or nearly the same, time would be useful. With data available at only a single frequency, there is an ambiguity of $n\pi$ in the determination of the total angle of rotation of the plane of polarization of a wave transmitted to the moon and back through the ionosphere.

The practical realizability of a linearly polarized, unidirectional antenna having essentially constant electrical characteristics over bandwidths of greater than ten to one in frequency was demonstrated in the fall of 1957.[1] Subsequent investigation had provided means of beamwidth control and improved impedance characteristics so that little development was required in designing the new feed.

The primary antenna is a nonplanar log-periodic antenna.[2] It is made up of two plane sheet-metal elements described in terms of the geometry of Fig. 3. The values of the various parameters used for this installation are $R_1 = 46$ in, $\tau = 0.7$, and $\alpha = 45°$. The elements are mounted on a bakelite pyramidal frame at an included angle $\psi = 60°$. The antenna is fed between the vertices of the two elements by means of a coaxial cable brought to the apex along one of the elements with its outer conductor bonded to the element. Note that no balun is required. It is the

Fig. 2—Log-periodic primary antenna.

property of log-periodic antennas of this type that at all frequencies greater than some low limit, determined by the maximum tooth length, only a portion of the elements is excited. As the frequency is varied, the current distribution along the elements remains nearly constant in terms of the wavelength.

The patterns of antennas of the type shown in Fig. 3 are characterized by a $\cos^n \theta$ shape in one hemisphere, with nearly equal principle plane beamwidths. The front-to-back ratio is approximately 15 db when the elements are mounted at an included angle ψ of about 2 α. The beamwidth under this condition is shown in Fig. 4 for several values of α. A dotted line through the points shows the variation to be nearly linear. It is possible to pick an α from this figure which corresponds to a particular illumination taper for a given f/d. By reducing the included angle ψ, the beamwidth in the H plane may be increased without changing the E-plane pattern so that equiamplitude contours in a plane perpendicular to the beam axis are elliptical rather than circular. The antenna

* Received by the IRE, March 2, 1959.
[1] D. E. Isbell, "Non-Planar Logarithmically Periodic Antenna Structures," Seventh Annual Symposium on the USAF Antenna Research and Development Program, Abstract, Monticello, Ill.; October, 1957. Also published by University of Illinois, Urbana, Antenna Lab. Tech. Rep. No. 30; February, 1958.
[2] Patent Pending, Ser. No. 768297.

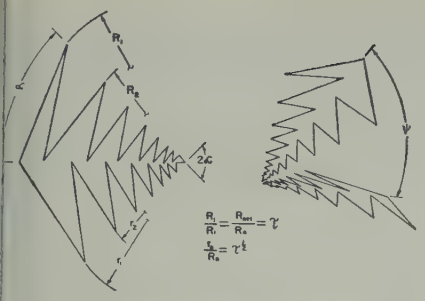

Fig. 3—Primary antenna parameters.

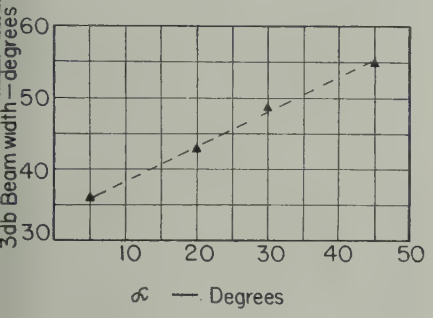

Fig. 4—Primary antenna beam width vs α, $\psi = 28$.

may thus be used to illuminate apertures other than circular with a reasonable degree of control in the amplitude at the edges.

The parameter τ corresponds to the periodicity of the structure. It has not been found to be critical and a value in the range 0.6 to 0.8 works well with α in the range 60° to 30°. If α is reduced while τ remains constant, the teeth tend to flatten out and lose their identity in which case the antenna ceases to function properly. This is avoided if the ratio τ is made to approach unity as α becomes small. If the aspect ratio of an individual tooth is defined as the ratio of its height to its width at the base, and τ is adjusted to provide an aspect ratio near unity or greater, the antenna will function properly. This condition is met if

$$\frac{2\tau^{1/2}\sin\frac{\alpha}{2}}{1-\tau} \geq 1.$$

A one-fourteenth scale model of the reflector and feed was used to measure secondary patterns over a band corresponding to the full scale range of 105 to 430 mc. The primary antenna was designed to provide a 10-db amplitude taper at the edges of the reflector as a compromise between gain and side lobe level. The half-power beamwidth of the secondary patterns is shown as a function of frequency in Fig. 5 for both E and H plane. The beamwidth decreases as frequency is increased in the expected manner up to about 325 mc beyond which it rises and then falls again. The problem here is primarily one of scaling. It has been found difficult to construct log-periodic antennas of the type here employed which provide the characteristic smooth, axially symmetric patterns much above 4000 mc. At about 4500 mc, 321 mc full scale, the primary patterns of the model feed were beginning to deteriorate as a result of this difficulty.

Taking as a reasonable approximation of the gain the ratio of 25,000 to the product of

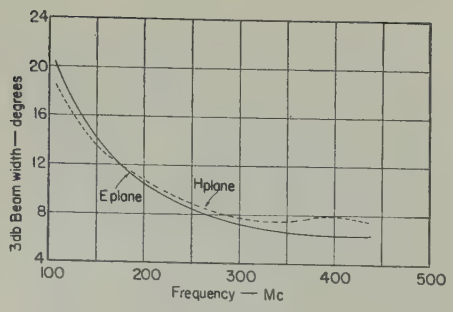

Fig. 5—Secondary pattern beam width.

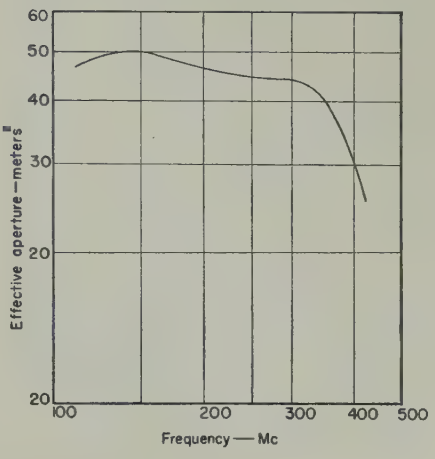

Fig. 6—Estimated effective aperture.

the half-power beamwidth in degrees and multiplying this result by $\lambda^2/4\pi$, a value for the effective aperture is obtained. The estimated effective aperture is plotted as a function of frequency in Fig. 6. Note that it is fairly constant in the band below 325 mc where the primary patterns of the model have not deteriorated.

The installation of the log-periodic feed in the University of Illinois antenna was completed in July, 1958, and has been in use since that time. In addition to "moon bounce" reception, it has been used for satellite tracking at 108 mc, and there are plans for its use in the range near 1000 mc.

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A Torsional Magnetostrictive Delay Line*

Pulses may be propagated along a wire delay line either in a longitudinal or a torsional mode. The torsional mode is preferred because of its lower velocity of propagation and its negligible dispersion factor.

Hitherto published methods of propagating torsional pulses use either barium titanate ceramic transducers[1] or longitudinal to torsional mode transformers.[2] Neither of these methods is readily adaptable for either a continuously variable or a multitap delay line. To overcome this disadvantage, a third technique may be used. In this technique, which is based upon the magnetostrictive phenomenon known as the Wiedemann effect, the conventional longitudinal coil transducers of a magnetostrictive delay line are replaced by toroidal coil transducers.

To generate the torsional pulse, a wire of magnetostrictive material, such as nickel, is initially biased within the transmitter toroid by both a longitudinal and a circular magnetic field in order to place the wire under torsional stress. The application of a pulse of electrical current to the transmitter toroid will change the amplitude of the circular magnetic field and produce a torsional pulse. This pulse will propagate along the nickel wire at a time delay of 8 μsec per in. As the pulse passes through the nickel wire within the receiver toroid, it will cause an incremental change in the amplitude of a biasing circular magnetic field which can be detected as a voltage pulse across the receiver toroid.

A basic delay line of this type is shown in Fig. 1. To provide the maximum magnetic flux leakage, the toroids are wound on bobbins of phenolic or equivalent material. The nickel wire threads through the toroids in close proximity to the individual turns of wire so as to obtain maximum magnetic coupling between the toroid and the nickel wire. The biasing circular magnetic field may be obtained by passing a dc current through the nickel wire, as shown in Fig. 1.

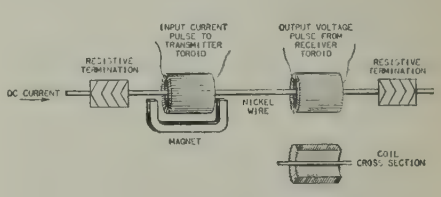

Fig. 1—Torsional magnetostrictive delay line with toroidal transducer coils.

Alternately, by introducing a dc current bias separately in each toroid, one can achieve independent amplitude control of the biasing circular magnetic field at each transducer. The biasing longitudinal magnetic field at the transmitter transducer is obtained from an external magnet.

The operational characteristics of the torsional magnetostrictive delay line are similar to those of the conventional longitudinal delay line in that maximum amplitude and minimum width of the output voltage pulse occur simultaneously when the width of the input current pulse is equal to the time of propagation through identical transducers. However, since the torsional time delay per unit length is greater than

* Received by the IRE, February 27, 1959.

[1] R. N. Thurston, and L. M. Tornillo, "Coiled wire torsional wave delay line," 1958 IRE National Convention Record, Pt. 2; p. 109.

[2] G. G. Scarrott, and R. Naylor, "Wire-type acoustic delay lines for digital storage," *Proc. of the IEE*, vol. 103, Pt. B, Supplement No. 3, Paper No. 2027M, p. 497; March, 1956.

the longitudinal time delay by a factor of 1.6, the length of the torsional transducer must be reduced in the same ratio for a given width of input current pulse. For an input current pulse of 2 μsec, for example, the length of the torsional transducer is 0.25 in. while the length of the longitudinal transducer is 0.4 in. However, it should be noted that in practice, the actual physical lengths must be reduced because of magnetic flux fringing at the ends of the transducers.

The author wishes to thank R. DeWitt of the ITT Laboratories for suggesting that the Wiedemann effect could be used to generate a torsional pulse in a magnetostrictive delay line.

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Enhanced Correlator Output Through Optimum Delay-Line Processing*

In dealing with stochastic time functions, it is often desirable to compute the cross-correlation function

$$\psi_{12}(\tau) = \lim_{T\to\infty} \frac{1}{T}\int_0^T f_1(t)f_2(t-\tau)dt, \quad (1)$$

where T is the integration time and τ is the delay, to obtain a measure of the statistical correlation between $f_1(t)$ and $f_2(t)$. We see from (1) that the operations of time delay, multiplication, and averaging are involved. The time delay and multiplication are physically realizable, but it is obviously not possible to average over infinite time. The errors due to finite observation intervals have been investigated by Davenport[1] and others, who have found for a "perfect integrator averaging filter" and very large T that the signal-to-noise ratio varies directly as $\sqrt{T}$.

In many physical situations, the stochastic time functions whose cross-correlation function we wish to compute may have been derived through processes employing the Doppler shift in which unequal spectrum shifts between $f_1(t)$ and $f_2(t)$ are introduced. In this case, excluding the effects of correlated noise, the cross-correlation function will vanish in the limit as $T\to\infty$. This is the aspect of correlation with which this paper is concerned, that is, the restoration of the stochastic time functions to their original spectral relationship.

Consider the stochastic variables $f_1(t)$ and $f_2(t)$ and their Fourier transforms $F_1(\omega)$ and $F_2(\omega)$. Let $f_2(t)$ incur a spectrum shift, α, such that its transform is now $f_2(\alpha\omega)$, and the inverse transform is

$$F_2^{-1}(\alpha\omega) = f_2\left(\frac{t}{\alpha}\right). \quad (2)$$

A spectrum shift in the frequency domain becomes a time compression or expansion in the time domain.

If the effects of noise are not considered, there will be no correlation should

$$\lim_{T\to\infty} \frac{1}{T}\int_0^T f_1(t)f_2(t-\tau)dt \neq 0 \quad (3)$$

for then

$$\lim_{T\to\infty} \frac{1}{T}\int_0^T f_1(t)f_2\left(\frac{t-\tau}{\alpha}\right)dt = 0. \quad (4)$$

The total spectrum change is

$$\Delta\omega = (\alpha - 1)\omega. \quad (5)$$

The inverse transform of ω is the unit doublet $u''(t)$ which in this case is dt. Hence the inverse transform of $\Delta\omega$ is

$$F^{-1}(\Delta\omega) = (\alpha - 1)dt \quad (6)$$

and the total delay time change,

$$\Delta\tau = \int_0^t (\alpha - 1)dt. \quad (7)$$

Thus if the delay in (1), τ, is varied in accordance with the negative of (7), the total effective change in τ will be zero.[2] The converse effect in the frequency domain will be the restoration of the original spectral relationship between $F_1(\omega)$ and $F_2(\omega)$.

Conclusion

The rate at which the delay of a correlator is varied is of prime importance. If the condition imposed by (7) is not met exactly, the integrand of the correlation function will tend to become oscillatory about zero, and a degradation in signal-to-noise ratio will result. The exactness with which (7) is implemented depends on the specific spectrum and also on the integration time, T. The longer the integration time, the closer $\Delta\tau$ must approximate (7). If a prior knowledge of (7) is not available, then all possibilities must be tried.

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[2] $\tau = \tau_0 + \Delta\tau$ where τ_0 is the delay at $T = 0$.

* Received by the IRE, March 2, 1959. Hudson Labs. Contribution No. 40. This research was sponsored by the Office of Naval Research, Washington, D. C.

[1] W. B. Davenport, Jr., "Correlator Errors Due to Finite Observation Intervals," M.I.T. Res. Lab. of Electronics, Cambridge, Mass., Tech. Rep. No. 191; March 8, 1951.

Radiometer Circuits*

Although the description given by the author[1] about the "alternate system" shown in his Fig. 1 is not exactly clear. I am convinced that he has made a rather serious error.

If Mr. Graham is correct, he has found a relatively simple way to eliminate noise in a finite time. For, if we follow his reasoning, by splitting a signal up into more and more parts, adding a new "uncorrelated" noise to each part, until the signal in each channel becomes infinitesimal and the noise continues to increase in proportion, we end up with an infinite signal-to-noise ratio.

The error which I believe Mr. Graham has made is not a new one. When information theory was in its infancy, some of our leading authorities fell into the same trap. The IRE would perform a service by pointing out the fallacy in Mr. Graham's letter so as to prevent engineers who are not experts on the subject of noise from falling into a similar trap.

Here, I believe, is the fundamental error. In thinking of cross-correlating two uncorrelated noise voltages, it is erroneous to assume that the resultant output noise *in a finite integration time* reduces to zero (independent of the delay τ). Furthermore, whenever the input signal is split into two channels, it is incorrect to assume that the average signal power in each channel is increased. Instead, the true situation is that the signal-to-noise ratio in each channel is *reduced* by virtue of the split input signal and *cannot* again be increased over single channel operation once nonlinear rectification has taken place.

A more detailed discussion of the problem may be found.[2]

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Author's Comment[3]

I believe Mr. George has incorrectly followed my reasoning. The figures presented in my letter[1] concern only the comparison of my proposed alternate system to the system originally given in a previous article.[4] The basic difference between these two systems is that the incoming signal power is wasted one half the total time in the square wave Dicke system, while in the alternate system, this power is utilized by a second receiver. There is no question involved of splitting the received signal $S(t)$ into more and more parts, but only the concept of utilizing the entire signal the entire time.

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* Received by the IRE, February 12, 1959.

[1] M. Graham, "Radiometer circuits," Proc. IRE, vol. 46, p. 1966; December, 1958.

[2] S. F. George, "Time Domain Correlation Detectors vs Conventional Frequency Domain Detectors," Naval Res. Lab., Washington, D. C., Rep. No. 4332; May 3, 1954.

[3] Received by the IRE, March 4, 1959.

[4] S. J. Goldstein, "A comparison of two radiometer circuits," Proc. IRE, vol. 43, pp. 1663–1666; November, 1955.

The Cause of Aurora Borealis*

The February, 1959 special issue of IRE Proceedings on the nature of the Ionosphere, calls to mind an item that may be of

* Received by the IRE, March 12, 1959.

nterest. One of the earliest uses of a vacuum ube was in connection with a study of aur- ral displays. During a survey of cathode ray ube applications made by the writer some hirty years ago, the following description f an early cathode ray tube was noted. It ppeared in the second volume of the *An- nual of Scientific Discovery* published in 1851, having been picked up from an earlier eport in 1850.

On The Cause of Aurora Borealis

With regard to the origin of the aurora borealis, it seems natural to attribute it to the electric field contained in the atmosphere, which at great heights, where the air is rarified, must become luminous, as under the receiver of an air-pump and in the barometer vacuum; this hypothesis would acquire a great probability if we succeeded in proving by direct experiments that magnetism exerts an influence upon electric light." This extract from a memoir by Morlet on the aurora borealis induced M. de la Rive to communicate the following experiment, showing the influence of magnetism on the light produced by ordinary electrical discharges. "I introduce into a glass globe, by one of the two tubulures with which it is furnished, a cylindrical iron bar, of such length that one of its extremities reaches nearly to the center of the globe, while the other extends a short distance out of the tubulures. The bar is hermetically sealed in the tubulure and covered throughout its length, except at its two ends with an insulating and thick layer of wax. A copper ring surrounds the bar above the isolating surface of its internal part the nearest to the side of the globe; from this ring proceeds a conducting rod, which, carefully isolated, traverses the same tubular as the iron bar, but without communicating with it, and terminates externally in a knob. When by means of a stopcock adjusted to the second tubulure of the globe, the air in it is rarified, the knob is made to communicate with one of the conductors of an electrical machine, and the external extremity of the iron bar with the other so that the two electricities unite in the interior of the globe, forming between the internal extremity of the iron bar and the copper ring which is at its base a more or less regular fascicle of light. But if the external extremity of the iron bar is placed in contact with one of the poles of a strong electromagnet taking good care to preserve the isolation the electric light takes a very different aspect. Instead of issuing, as before, from the different points of the surface of the terminal parts of the iron bar it is emitted only from the points which form the contour of this part so as to constitute a continuous luminous ring. This is not all; this ring and the luminous jets which emanate from it have a continuous movement of rotation around the magnetized bar, now in one direction, now in another, according to the electric discharges and the direction of the magnetization. Lastly, more brilliant jets appear to issue from this luminous circumference, without being confounded with those which terminate on the ring and from the fascicle. As soon as magnetization ceases, the luminous phenomena becomes again what it was previously, and what is generally in the experiment known as the electrical egg.—*Silliman's Journal; May, 1850*

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The Calculation of the Field in a Homogeneous Conductor with a Wavy Interface*

It is well known that electromagnetic waves are attenuated exponentially below the plane interface of a homogeneous conductor. For example, if radio waves are propagating along the surface of a flat well-conducting ground, the field component ψ at depth h is related to the same field component ψ_0 at the interface by the simple relation[1]

$$\psi \cong \psi_0 e^{-(\gamma^2-k^2)^{1/2}h} \cong \psi_0 e^{-\gamma h}. \quad (1)$$

In the above, $k=2\pi/\lambda$ where λ is the wavelength in air and γ is the complex propagation constant given by

$$\gamma = [i\mu\omega(\sigma + i\epsilon\omega)]^{1/2}$$

in terms of the angular frequency ω, conductivity σ, permeability μ, and permittivity ϵ.

Eq. (1) is also valid in a local sense for a gently undulating surface if the local radius of curvature is large compared to both $|\gamma^{-1}|$ and h. This statement, if not obvious, follows immediately from the work of Leontovich.[2]

In most cases of practical interest, the displacement currents are negligible compared with the conduction currents. Thus $\sigma \gg \epsilon\omega$ and consequently

$$\gamma \cong (i\sigma\mu\omega)^{1/2} = (1+i)/\delta$$

where $\delta=(2/\sigma\mu\omega)^{1/2}$ is the classical "skin depth."

We now wish to calculate the field at any depth in a homogeneous conductor which has a gently undulating or wavy interface. For illustration, the interface between the conductor and the air above it is taken to be sinusoidal in form. This might be a fair representation for the ocean. This idealized situation is illustrated in Fig. 1. The waves are two dimensional in form so that, in terms of a rectangular coordinate system, the interface is described by

$$z = D\cos(2\pi x/L) = D\cos\beta x \quad (2)$$

where D is the amplitude, L is the period, and $\beta=2\pi/L$.

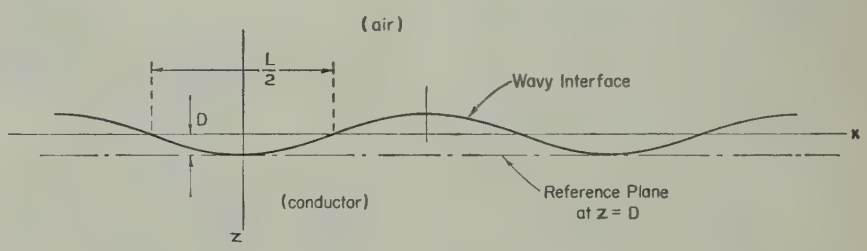

Fig. 1.

It is now assumed that the field in the air above the interface is of the form

$$\psi_0 e^{-ik_1 x} e^{-ik_2},$$

being a uniform plane wave traveling in a direction parallel to the mean interface, *i.e.*, the plane $z=0$. This assumption is justified if the free-space wavelength λ is large compared to the period L of the waves and if the height of the waves is small compared to their period, *i.e.*, $D \ll L$. Under these assumptions the field $\psi_r(x)$ along a reference plane $z=D$ in the conductor can be written:

$$\psi_r(x, y) \cong \psi_0 e^{-ik_1 x} e^{-ik_2 y} e^{-\gamma D(1-\cos\beta x)}.$$

The latter exponential factor accounts for the attenuation of a wave traveling vertically, or near vertically, downward from the interface to the reference plane $z=D$. This concept is valid since D is always much less than the radius of curvature of the interface.

The solution is facilitated by rewriting $\psi_r(x,y)$ in the series form

$$\psi_r(x, y) = \psi_0 e^{-ik_1 x} e^{-ik_2 y} e^{-\gamma D} \sum_{n=-\infty}^{+\infty} I_n(\gamma D) e^{i\beta n x} \quad (3)$$

using an addition theorem[3] for modified Bessel functions $I_n(\gamma D)$ of order n and argument γD. Now the field $\psi(x, y, z)$ is a solution of

$$\left(\frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2} + \frac{\partial^2}{\partial z^2} - \gamma^2\right)\psi(x, y, z) = 0 \quad (4)$$

for $z \geqq D$ and, therefore, it is of the form

$$e^{i(\beta n - k_1)x} e^{-ik_2 y} e^{-\alpha_n z}$$

where

$$\alpha_n = [(\beta n - k_1)^2 + k_2^2 + \gamma^2]^{1/2}.$$

Since $\psi(x, y, z)$ is to reduce to $\psi_r(x, y)$ for $z=D$, it easily follows that

$$\psi(x, y, z) = \psi_0 e^{-ik_1 x} e^{-ik_2 y} e^{-\gamma D} \times \sum_{n=-\infty}^{+\infty} I_n(\gamma D) e^{i\beta n x} e^{-\alpha_n(z-D)} \quad (5)$$

which is of the required form. It is immediately seen that, if D approaches zero,

$$\psi(x, y, z) \cong \psi_0 e^{-ik_1 x} e^{-ik_2 y} e^{-\gamma z}, \quad (6)$$

as expected. In general, when D is finite, the field is no longer characterized by a single exponential term.

The general formula is simplified somewhat if it be noted that in cases of practical interest $\beta \gg k_1$ and k_2. This inequality is satisfied if $\lambda \gg L$. Then

$$\psi(x, y, z) = \psi_0 e^{-ik_1 x} e^{-ik_2 y} e^{-\gamma D} \times \sum_{n=0}^{\infty} \epsilon_n I_n(\gamma D)\cos(\beta n x) e^{-[(\beta n)^2+\gamma^2]^{1/2}(z-D)} \quad (7)$$

where $\epsilon_0=1$ and $\epsilon_n=2$ for $n=1, 2, 3$. For computation[4] we can make use of the series formula

$$I_n(\gamma D) \cong \frac{(\gamma D)^n}{n!\,2^n} + \frac{(\gamma D)^{n+2}}{(n+1)!\,2^{n+2}} + \cdots \quad (8)$$

which converges rapidly if $|\gamma D| < 1$. In fact, if $|\gamma D| \ll 1$ or if $D \ll \delta$, the field in the conductor can be written

* Received by the IRE, December 16, 1958.

[1] J. R. Wait, "Theory of electromagnetic surface waves over geological conductors," *Geofisica Pura e Applicata*, vol. 28, pp. 47–56; 1954.

[2] M. A. Leontovich, "Approximate boundary conditions," in "Investigations on Radiowave Propagations," Printing House of Academy of Sciences, Moscow, U.S.S.R., pt. II, pp. 5–12; 1948.

[3] N. W. McLachlan, "Bessel Functions for Engineers," Oxford University Press, New York, N. Y.; 1934.

[4] Also note that

$$I_n(\gamma D) \cong I_n(i^{1/2}Z) = \frac{1}{i^n}[\mathrm{ber}_n Z + i\,\mathrm{bei}_n Z]$$

where $Z=|\gamma D| = \sqrt{2}D/\delta$ and where ber_n and bei_n are tabulated by McLachlan, *op. cit.*

$$\psi(x, y, z) = \psi_0 e^{-ik_x x} e^{-ik_y y} \times [e^{-\gamma z} + (\gamma D) e^{-\gamma D} e^{-\sqrt{\gamma^2+\beta^2}(z-D)} \cos \beta x \quad (9)$$
$$+ \text{higher order terms in } |\gamma D|.$$

This clearly shows that the perturbation due to the ripples is proportional to the amplitude D of the waves. It is also noted that the first perturbation term varies sinusoidally with x following the form of the wavy interface.

This problem was suggested to me by A. D. Watt.

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Phase Relationships at the Output of a Short Slot Hybrid Junction*

Prompted by conflicting statements in the literature,[1-3] a study has been made of the phase relationships at the output ports of short slot couplers. From a consideration of the phase velocity of the modes established in the coupling region of the short slot hybrid, it can be shown that, with an input to port 2 (Fig. 1);

1) for the *sidewall* coupler, the output of the main guide (port 4) will *lead* the output of the auxiliary guide (port 3) by 90 degrees,

2) for the *topwall* coupler, the output of the main guide will *lag* the output of the auxiliary guide by 90 degrees.

This conclusion was expressed by Mattingly, *et al.*,[3] but contradicts Riblet[1] and Strom.[2]

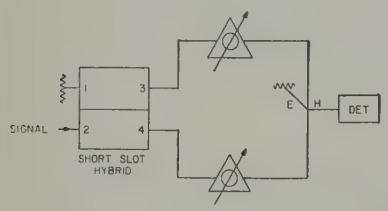

Fig. 1—Microwave bridge circuit for measuring phase relationships.

The findings have been verified by two experimental measurements. One method involved the use of the microwave bridge circuit shown in Fig. 1. With approximately equal lengths in the bridge arms (within 0.1 wavelength), excitation of port 2 of the short slot coupler will produce some output from the H-arm of the magic-T. By changing the length in either arm of the bridge and observing the change in the output of the magic-T, the phase relationship of the outputs of the short slot coupler can be immediately deduced. This experiment shows that in-phase conditions at the magic-T are produced when the length of the arm connected to port 3 is decreased for the sidewall coupler and increased for the case of the topwall coupler, indicating a lagging phase from the auxiliary arm (port 3) of the sidewall coupler and a leading phase from the same port of the topwall coupler.

Another experimental method, used to resolve the question of output phase relationships, required taking antenna patterns of an open-ended short slot coupler excited from one opposing port. In this case, the hybrid ports radiate as a two element array with a 90 degree phase difference between elements. This phase difference will shift the point of maximum intensity away from the array axis in the direction of the element which has the lagging excitation. The angle off axis will, of course, be determined by the array geometry and the frequency of operation. In addition to a point of maximum intensity, a null is to be expected in the radiation pattern corresponding to the angle at which the signals from the two elements are 180 degrees out of phase. Trigonometric considerations require that, for a 90 degree phase difference, the angle of the null with respect to the axis should be the negative of the angle of the maximum also referred to the axis. The antenna patterns shown in Figs. 2 and 3 illustrate the shift which is to be expected from the phase relationships obtained analytically. In addition, the angular relationship of the maximum and minimum is clearly evident.

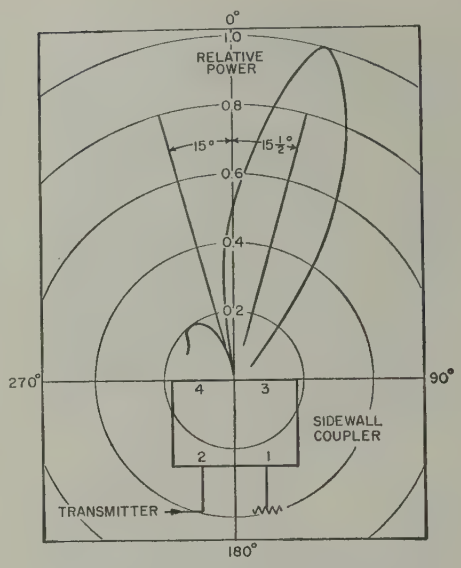

Fig. 2—Radiation pattern for sidewall coupler showing phase lead in main guide.

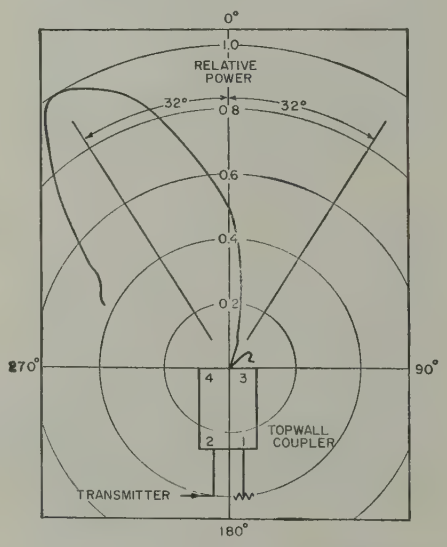

Fig. 3—Radiation pattern for topwall coupler showing phase lag in main guide.

The absolute phase relationships have been found to be in contradiction to those of Riblet[1] and Strom[2] but, a rigorous analysis of various microwave circuits using both concepts has shown that the difference in solutions is primarily one of polarity. It should be noted that the relative difference in output phase is the important factor to be recognized in designing microwave circuits which utilize both types of couplers.

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Radio Reflections from Satellite-Produced Ionization*

In the past few months a great deal of interest has been aroused concerning the effects of earth orbiting satellites on the upper atmosphere or ionosphere. It has been speculated that enough ionization could be produced by the motion of a satellite through the upper atmosphere to produce a plasma of ionized particles capable of returning electromagnetic waves to earth. If such a plasma exists, its critical frequency appears to be below the VHF region since various types of radar have thus far indicated cross sectional areas which are close to the skin dimensions of the tracked orbiting vehicles.

Several attempts have been made to prove (on a scientific basis) that such low frequency effects exist. Observers have reported both positive and negative results by making observations of signals received from continuously transmitting radio stations. The principal source of energy in several cases has been the 20 mc WWV transmitter.

In October, 1958, the authors under the sponsorship of General Electric's Light Military Electronics Department initiated a project for making such observations. However, the search for reflected signals was not limited to 20 mc; observations were also made on the 5, 10, and 15 mc WWV transmitters, which seemed to be well located for such use. From preliminary data obtained it appears that disturbances do exist which are correlated with satellite

* Received by the IRE, April 15, 1959.

* Received by the IRE, December 29, 1958.

[1] H. J. Riblet, "The short-slot hybrid junction," Proc. IRE, vol. 40, pp. 180–184; February, 1952.

[2] L. D. Strom, "Noise cancellation in microwave mixers," *Tele-Tech and Electronic Indus.*, vol. 15, pp. 186–188; March, 1956.

[3] R. L. Mattingly, B. McCabe, and M. J. Traube, "The split reflector technique for broadband impedance matching of center-fed antennas without pattern deterioration," IRE Wescon 1957 Convention Record, vol. 1, pt. 1, pp. 231–235.

ssages. Through the use of the various equencies, more than one type of corre- ted disturbance has been observed. On the mc frequency a fast flutter phenomenon s been observed, as has been previously ported. However, at 15 mc, and especially 10 mc, two very different types of dis- rbances have been found.

The first phenomenon observed at 10 mc ffers from the flutter-type reflections ob- ined at 20 mc in that the signals received hibit characteristics which change fre- uency. This frequency change is similar to hat which would be obtained from a trans- itter aboard the satellite itself and for this eason has been called a "Doppler" reflec- on. This reflection has been observed to roduce an audible beat with the WWV car- er received by sky wave.

The Doppler-shifted reflected signal, hen observed on a spectrum analyzer, is een to consist of a smear of frequencies 50– 00 cycles wide, moving as would be ex- ected, from a few hundred cycles gradually hrough zero beat, and up again. As might e anticipated, observations indicate that he Doppler is heard more often at night. he density of the plasma partially sur- ounding the orbiting vehicles is probably nough for reflections at this frequency but is obscured during the day because of nospheric influence.

The second observed phenomenon is in he form of a delayed disturbance. This ef- ect is a rough audio note containing com- onents between 60 and 400 cycles. It is elayed approximately 8–10 minutes after nown satellite passages (and after the Doppler disturbance). The frequency dis- ribution remains relatively constant with ime, and for this reason the effect has been alled a "rumble." The duration of "rum- le" varies from a few seconds to nearly one inute. There are several clues regarding he explanation of the rumble, but nothing onclusive as yet.

The effects described have been heard on 0 and 15 mc. However, generally speaking he disturbances observed on 15 mc have een much less frequent and considerably eaker. It has been found that the rumble is ore consistent in its appearance than the Doppler" and on the lower passes of the tellites it generally appears both day and ight. As yet the rumble has never been bserved previous to a satellite passage.

To date no extensive effort has been ade to explain the Doppler and the rumble isturbances although a large number of bservations have been made on satellites 958 delta 1 and 2 (the two components of putnik III). The data which have been ob- ined have been compared with the sched- led passes of the satellites as well as with e Doppler signal taken directly from the 958 delta 2 transmitter and are presently eing analyzed more extensively.

An interruption in the study was re- ently made to apply the not yet proven chnique on the lost satellite, 1959 beta Discoverer I). This was done because the dio of the satellite was for all practical rposes unable to report the satellite's sition, and the orbit plane was such that was not visible over most of the area of e earth. Day and night listening periods ere set up in Ithaca and Schenectady, N. Y. Extremely good results were obtained using the 10 mc reflected signals. For a period of over 2 weeks consistent returns were obtained with a periodicity that correlated very closely with the period predicted from the launch data obtained from the Air Force. The rumble effect was very consistent. The Doppler returns, although not obtained on every pass of the satellite, definitely existed and at times lasted for up to 5 minutes.

The purpose of continuing the study now in progress is to determine the cause of the phenomenon. However, from the work accomplished thus far it appears that observed signal disturbances are definitely correlated with actual satellite passes.

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WWV Standard Frequency Transmission*

Since October 9, 1957, the National Bureau of Standards radio stations WWV and WWVH have been maintained as constant as possible with respect to atomic frequency standards maintained and operated by the Boulder Laboratories, National Bureau of Standards. On October 9, 1957, the USA Frequency Standard was 1.4 parts in 10^9 high with respect to the frequency derived from the UT 2 second (provisional value) as determined by the US Naval Observatory. The atomic frequency standards remain constant and are known to be constant to 1 part in 10^9 or better. The broadcast frequency can be further corrected with respect to the USA Frequency Standard, as indicated in the table below. This correction is *not* with respect to the current value of frequency based on UT 2. A minus sign indicates that the broadcast frequency was low.

WWV FREQUENCY†

1959 March	Vs NBS‡ Atomic Standards 30-Day Moving Average Seconds pulses at 15 Mc	Vs Atomichron at WWV Measuring Time 1 Hour 2.5 Mc	Vs Atomichron at NRL Measuring Time 56 Minutes 2.5 Mc
1	−37	−40	
2	−37	−40	36
3	−37	−40	36
4	−36	−39	36
5	−35	−39	36
6	−35	−40	36
7	−34	−39	
8	−33	−39	
9	−33	−39	36
10	−32	−39	36
11	−32	−39	35
12	−32	−39	35
13	−32	−38	34
14	−32	−39	
15	−32	−39	
16	−32	−38	34
17	−32	−38	34
18	−32	−38	35
19	−32	−38	33
20	−33	−38	
21	−33	−38	
22	−32	−37	
23	−32	−38	35
24	−32	−38	35
25	−32	−38	35
26	−32	−38	35
27	−32	−38	34
28	−31	−38	
29	−31	−37	
30	−31	−37	35
31	−31	−38	36

The WWV and WWVH time signals are synchronized; however, they may gradually depart from UT 2 (mean solar time corrected for polar variation and annual fluctuation in the rotation of the earth). Corrections are determined and published by the US Naval Observatory.

WWV and WWVH time signals are maintained in close agreement with UT 2 by making step adjustments in time of precisely plus or minus twenty milliseconds on Wednesdays at 1900 UT when necessary; no time adjustment was made during this month at WWV and WWVH.

National Bureau of Standards
Boulder, Colo.

* Received by the IRE, April 24, 1959.
† WWVH frequency is synchronized with that of WWV.
‡ Method of averaging is such that daily adjustments appear in the data on the day they are made.

The Need for Revision of Transistor Terminology and Notation*

Congratulations to Armstrong for his excellent article on the need for revising transistor terminology and notation.[1]

Like Armstrong, I also have been teaching a course in transistor electronics and am in hearty agreement with most of his remarks. However, I am not quite in agreement with his statement that for quotation, the h parameters should be converted into whatever set will be most immediately useful to the user. How does a manufacturer know that the designer will be concerned only with the transmission parameters? Armstrong himself points out earlier in his article that the Y and Z matrices also are useful.

This brings up a closely related point: the failure of most manufacturers to publish adequate data on the transistors they make. Frequently one will receive a data sheet which shows a circuit designed around a given transistor, its temperature, voltage, and current limits and perhaps the h parameters at a particular operating point. This is all well and fine if the user is interested only in the particular circuit shown. Suppose he has another application in mind, however? Perhaps he is interested in linearity about some different operating point, or perhaps in low-frequency noise fluctuation or some other quantity.

Such added information assuredly will require more work on the part of manufacturers, but should net them correspondingly increased applications, which I am certain they will welcome. To me, adequate infor-

* Received by the IRE, January 5, 1959.
[1] H. L. Armstrong, "On the need for revision in transistor terminology and notation," Proc. IRE, vol. 46, pp. 1949–1950; December, 1958.

mation is just as important as uniform terminology, if not more so.

To return to the problem of terminology and notation, I have observed also a lack of uniformity in sign conventions. These should be standardized along with the notation.

In conclusion, I agree with Armstrong that it is undesirable to try to standardize things too quickly in a new field. However, transistor electronics has advanced to the point that standardization is imperative—now.

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Author's Comment[2]

Naturally, the author is happy to hear that Keiser agrees with many of his views on transistor notation and terminology. Perhaps if enough of us feel the same way, something may be done to end the present confusion.

Actually, I think we are in essential agreement. My quarrel with the h parameters is not with them as pieces of information—they may be most useful pieces of information—but rather with the notation. To present them as matrix elements, when in fact they will probably never be used in matrix analysis, seems useless. In particular, it requires two subscripts. If, then, one or two additional subscripts should be required to distinguish stages, operating conditions, etc., the result is quite a mess.

I could not agree more with Keiser on the frequent dearth of information on transistor types. The same situation seems to arise sometimes with new tube types. I have sometimes wished to use, in pulse circuitry, tubes such as sweep tubes and damper diodes, intended originally for use in television receivers. Only too often the only information readily available is that dealing with that use alone.

Certainly it should be safe to do some standardizing on transistor electronics now. My comments on this matter were intended to suggest that in some really new field, say cryotrons or masers, we should go very cautiously in trying to standardize terminology and notation.

May I add here one final word of explanation about my comment on the B and H fields? I am aware that recently a number of excellent articles and books have made the correct distinction here. Actually, my comments were prompted by exasperation at reading a proposed standard, which called the field H when it should have been B. After all, if the standards do not treat these matters correctly, who is to show the way?

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[2] Received by the IRE, January 30, 1959.

Semantics and Kirchhoff's Current Law*

Kirchhoff's current law is usually stated thus: the sum of the currents entering a node equals the sum of the currents leaving; or the algebraic sum of the currents entering a node is zero.

Thus, if any part of a network is enclosed by a surface the algebraic sum of the currents entering the surface is zero. In the case of lumped elements, the set of branches crossing such a surface forms a cut set and if the network possesses a dual, the dual of the cut set is a tie set. A tie set is associated with a loop and this loop may be considered as a graphical analog of the tie set. The graphical analog of a cut set is the surface referred to above and the purpose of this note is to suggest a name for it.

Since a circuit diagram is usually drawn on a flat surface, the surface in question degenerates to a closed path that encloses a part of the network. It is, in fact, a circuit defined by the branches it crosses. An appropriate name for this circuit is ambit.[1] This is a perfectly good English word that means a circuit, circumference, or boundary. As applied to networks in general, an ambit is a closed surface that separates a network into two parts. It is sufficient for most purposes to think of it as a closed path formed by cutting branches. The branches crossed by an ambit are said to belong to the ambit or to be contained in it. For example, a set of branches contained in an ambit forms a cut set.

A few examples will illustrate the utility of the ambit concept. Evidently, Kirchhoff's current law may be stated—the sum of the currents entering an ambit equals the sum of the currents leaving it or, the algebraic sum of the currents entering an ambit is zero. Concerning duality, we may say that two graphs are duals if to every ambit in one there corresponds a loop in the other and vice versa.

The ambit notion is especially useful when writing equilibrium equations using as variables node-pair voltages other than node-to-datum voltages. Fig. 1 illustrates this point. Here a tree has been selected (solid lines) and the tree-branch voltages are used as variables. Ambits are selected in such a way that each contains only one tree branch. To write the equilibrium equations, a current-law equation is written for each ambit, expressing the branch currents in terms of the branch conductances and the appropriate voltages. Thus, for ambit one we have

$$E_1G_1 + (E_1 - E_2)G_5 + (E_1 - E_2 + E_3 + E_4)G_7 = J_1 \quad (1)$$

in which each term represents a current flowing away from the ambit. Similarly, for ambit two we obtain

$$E_2G_2 + (E_2 - E_1)G_5 + (E_2 - E_1 - E_3 - E_4)G_7 + (E_2 - E_3)G_8 = 0. \quad (2)$$

* Received by the IRE, February 9, 1959.

[1] This particular word was suggested by H. E. Meadows, Jr., Bell Telephone Labs., Murray Hill, N. J.

In this equation positive currents are considered to be flowing into the ambit. This is done in order to make the coefficient of E_2 positive. Now, collecting similar terms in these equations gives

$$E_1(G_1 + G_5 + G_7) - E_2(G_5 + G_7) + E_3G_7 + E_4G_7 = J_1 \quad (3)$$

$$-E_1(G_5 + G_7) + E_2(G_2 + G_5 + G_7 + G_8) - E_3(G_7 + G_8) - E_4G_7 = 0 \quad (4)$$

and the two remaining equations are readily found to be

$$E_1G_7 - E_2(G_7 + G_8) + (G_3 + G_6 + G_7 + G_8) + E_4(G_6 + G_7) = 0 \quad (5)$$

$$E_1G_7 - E_2G_7 + E_3(G_6 + G_7) + E_4(G_4 + G_6 + G_7) = -J_2. \quad (6)$$

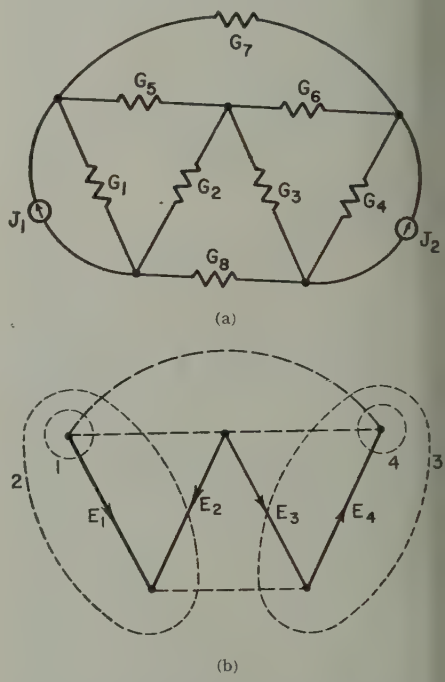

Fig. 1—A network and its graph showing ambits associated with tree branches. Reference arrows show positive directions for tree-branch currents. The E's are the corresponding tree-branch voltages. J_1 and J_2 are current sources.

It is easy to devise a set of rules for writing the final equations by inspection. Noting that each equation is of the form

$$\sum_{k=1}^{n} G_{sk}E_k = J_s \quad (7)$$

it is apparent that G_{sk} is the sum of all conductances common to ambits s and k. G_{ss} is always positive. G_{sk}, for $s \neq k$, is positive if the reference arrows for E_s and E_k have the same direction along a tree-branch path from ambit s to ambit k; otherwise, it is negative. J_s is positive if its direction is opposite to the current reference direction for E_s; otherwise it is negative.

The rules are readily modified to include voltage as well as current sources, no source transformations being required. Also, if the

ee is selected so that its branches have a ommon node, the ambit equations are iden-cal to the familiar node equations.

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A Compact Antenna Switch for Scintillation Measurements*

In meter wave radio interferometers modulation of discrete radio source signals may be obtained by alternately reversing the phase of the signal from one of the antennas. This is usually accomplished by introducing one half-wavelength of cable into one of the antenna leads. A more compact switch may be constructed if a phase shift of $\pi/2$ radians is introduced into each of the antenna lines in turn. This method is not generally recommended since the parallel impedance of the two antennas may not be the same for each position of the switch resulting in changes in the internal noise power of the receiver at the switching frequency.[1] However, when recording scintillating signals from strong radio sources, the effect of such changes is small and virtually constant.

The switch, which was designed to be part of a portable scintillation recorder, is shown in Fig. 1. The two antenna cables are

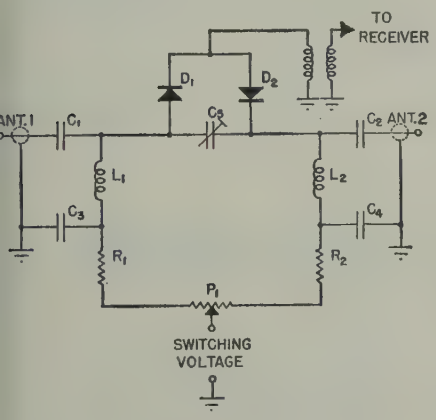

Fig. 1.

joined by an artificial quarter-wave section of line consisting of L_1, L_2, and C_5, the receiver input being alternately connected to either end of this line by the switching diodes D_1 and D_2. The capacitors C_1, C_2, C_3, C_4 are blocking capacitors whose reactance should be small at the signal frequency and large at the switching frequency. The resistors R_1 and R_2 limit the maximum forward current through the diodes and P_1 is a balancing potentiometer which is adjusted for zero modulation of the background signal.

D_1 and D_2 are 1N91 junction diodes. At 50 mc the 1N91 has a low resistance of the order of several ohms when biased in the forward direction. With reverse bias the diode exhibits a capacitive susceptance of about 5 millimhos. In the design, the forward resistance may be neglected and the reverse susceptance assumed to be part of C_5. The diodes should be relatively well matched although small differences may be compensated by adjustment of P_1 and if necessary by trimming capacitors.

Measurements were made on a switch designed to operate at 50 mc. In the frequency range 40 mc to 60 mc, the phase shift obtained was found to be very closely that which would be produced by a corresponding length of coaxial cable, while the insertion loss was less than 1.5 db. The noise produced by the switch is low since the diodes are mismatched in both the forward and reverse directions.

The author wishes to thank G. A. Harrower, Director of the Queen's University Radio Observatory for providing the facilities for testing the above switch.

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* Received by the IRE, February 9, 1959.

[1] M. Ryle, "A new radio interferometer and its application to the observation of weak radio stars," *Proc. Roy. Soc.*, pt. A, vol. 211, pp. 351–375; March, 1952.

An Historical Note on Graphical Representation*

It is always interesting and somewhat surprising to find similar mathematical tools in various fields of engineering and science. One of the most striking examples of this is obtained from the diagrams in Sommerville's book,[1] which was written in 1914 and recently republished. These diagrams are identical to the bicircular chart, the Smith Chart, and Deschamps' construction for the iconocenter of a loss circle. The bicircular chart is the representation of concentric non-euclidean circles all of which cut orthogonally a pencil of lines from a common vertex. The loci of constant VSWR are the concentric circles, and the loci of constant phase angles are the lines of the pencil centered at Z_0. The Smith Chart is similar (geometrically) to the bicircular chart except that the vertex of the pencil is moved to a point at infinity (the rim of the unit circle). Therefore, the constant resistance circles (or horocycles) are all centered at their point of intersection. The lines of the pencil from the center of the non-euclidean concentric circles represent the constant reactance lines of the Smith Chart.

Deschamps' construction for the iconocenter determines the non-euclidean center of the loss circle.

This short note is written to illuminate some of the interesting relationships between the graphical representations employed in microwave networks and those of the non-euclidean geometry.

It is felt pertinent to do so in view of the recent interest in the subject.

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*Received by the IRE, February 25, 1959.

[1] D. M. Y. Sommerville, "The Elements of Non-Euclidean Geometry," Dover Publications, Inc., New York, N. Y., pp. 177–179.

Binary Multiplication in Digital Computers*

One of the most basic arithmetic operations required from a Digital Computer is that of binary multiplication; yet, the multiplier in most computers does not actually go through the process of multiplying, but rather through a process of successive additions, the final sum of which is equal to the respective product. Actually, by using successive additions in order to multiply two numbers, the computer imitates the human "multiplier" in a somewhat primitive though faster way.

The human mind would multiply two binary numbers in the following fashion (Example 1): the multiplication of the multiplicand by each digit of the multiplier produces an "intermediate product." Such products are placed one underneath the other so that each "intermediate product" associated with a digit of the multiplier is below, and shifted one digit to the left, in respect to intermediate product associated with the next higher significant digit of the multiplier. Furthermore, if the digit in the multiplier is "1," its corresponding "intermediate product" is the exact duplicate of the multiplier, while when it is "0," its corresponding "intermediate product" is merely a row of zeroes. All the "intermediate products" are then added, and the result is the final product.

Example 1

multiplicand	110
multiplier	011
intermediate products	110
	110
	000
final product	10010

The Digital Computer operates in a similar fashion, except that it shifts to the right the "intermediate product" corresponding to the lower significant figure of the multiplier, rather than shifting to the left the one associated with the higher significant figure. The basic difference is that the final addition is not done after all "intermediate products" are obtained, but an "intermediate addition" is done after each "intermediate product" is registered, the last one of such "intermediate sums" being the final product (Example 2).

* Received by the IRE, December 29, 1958.

Example 2

```
                 110
                 011
                 ---
                 110  ........intermediate product 1
intermediate  { 110  ........shift to right
  addition 1  {110   ........intermediate product 2
                 ---
                10010 ........intermediate sum 1
intermediate  {10010........shift to right
  addition 2  {000   ........intermediate product 3
                 ---
                10010........intermediate sum 2
                             =final product
```

A comparison between the conventional computer and the human mind shows that the computer is inferior to the man because of two reasons:

1) It cannot "write" a "pre-shifted" number;
2) It cannot add more than two numbers simultaneously.

Example 1 can be rewritten in the following manner: the digits of the multiplicand are written above the intermediate products with an ascending order of significance from left to right. The multiplier digits are written vertically on the left of the intermediate products with an ascending order of significance from top to bottom (Example 3).

Example 3

```
                 110          multiplicand
                 ---
multiplier......{1-  110 }
                {1-  110 }.....intermediate
                {0-  000 }      products
                 ---
                 10010        final product
```

Whenever the multiplier digit is "1," the intermediate product on its right is a duplicate of the multiplicand. Whenever the multiplier digit is "0," the intermediate product on its right is a row of zeroes. The final product is obtained by adding the intermediate products along the marked diagonals.

It is clearly seen from Example 3, that by properly connecting the wires in the computer, the shifting process can be disposed of. It shall be shown later that the intermediate additions are also superfluous.

By eliminating the handicaps listed above, the computer becomes—as far as multiplication is concerned—just as "intelligent" as the man. There is no reason, however, why the computer cannot be "wiser" than a man, and one way to make it superior to a man is by parallel multiplication.[1] It will be shown that a computer can calculate and store all the "intermediate products" in a single operation, and then add all those products simultaneously, thereby achieving the final product.

The first stage of such a multiplier (Fig. 1) consists of a matrix of vertical and horizontal wires, with an "and" gate in each intersection. The multiplicand is fed to the vertical wires and the multiplier to the horizontal ones in the same fashion as written in Example 3. Both multiplicand and multiplier are fed into the matrix simultaneously. The "and" gates in the intersections of two wires carrying a "1" input, produce "1" outputs. All other gates produce "0" outputs. Thus, the "and" gates in the matrix display electrically the same array of "intermediate products" as written in Example 3.

The second stage of the multiplier is the simultaneous adder (Fig. 2). The heart of this circuit is a counter, with multiple inputs and outputs. The output wires signify a number from 0 to n corresponding to the number of energized input wires. Such a counter can be a symmetrical relay or magnetic core circuit, or a complete decoding matrix with all outputs with the same number of "ones" "or"ed together. The readout wires 1–9 in Fig. 1 are fed into the adder in groups, each group consisting of the readout wires belonging to one diagonal path in Fig. 1. The signals on each diagonal group are delayed by one time unit in respect to the signals on the group of the lesser order of significance. The outputs representing 2 and 3 inputs are fed back to the input of the counter, and are delayed one time unit so as to give one "carry" together with the next group of inputs. Outputs for 4 and 5 inputs are fed back the same way to give 2 "carries," outputs 6 and 7 give 3 "carries," etc. All even outputs are also connected to the "0" lead of a shift register, and all the odd outputs to the "1" input of a shift register.

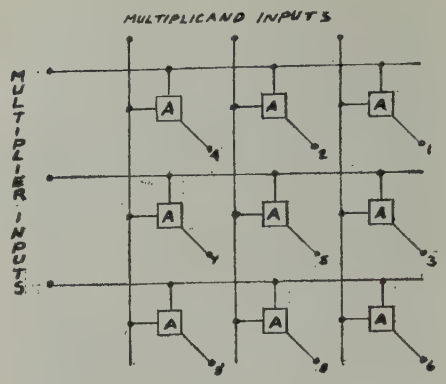

Fig. 1.

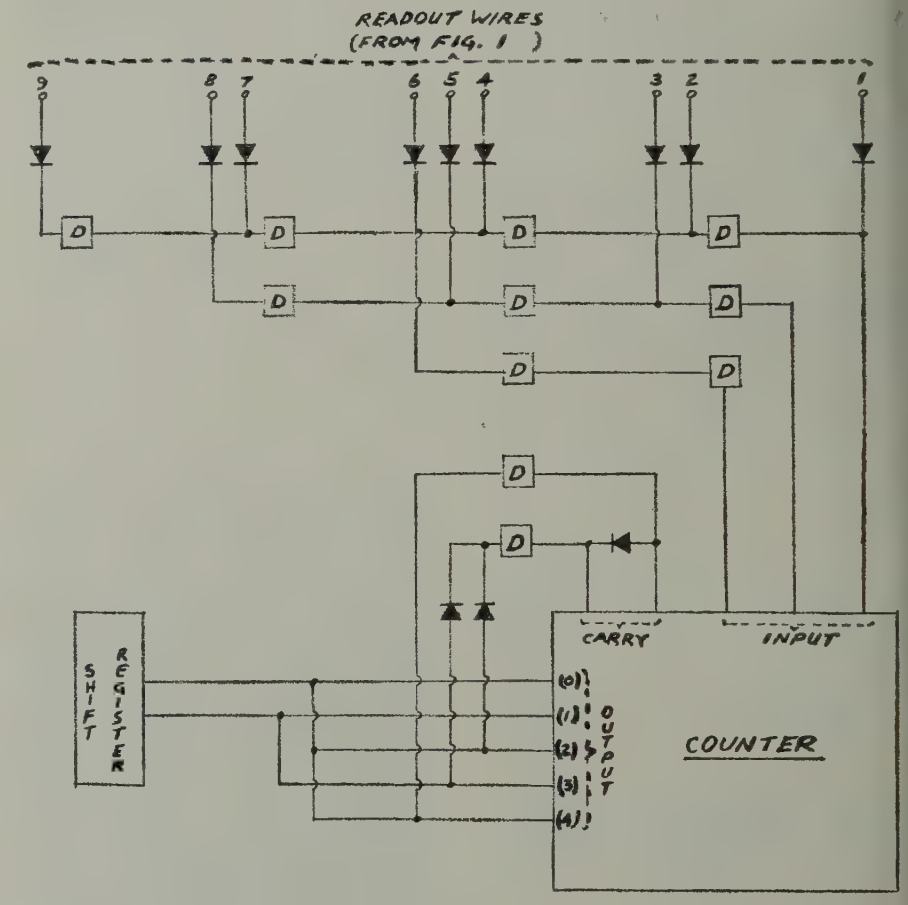

Fig. 2.

To follow our numerical example, readout lead no. 1 (Figs. 1 and 2) is "0," therefore the "0" output lead of the counter will be energized and register a "0" in the shift register. Readout leads 2 and 3 are "1" and "0" respectively. The "1" on lead no. 2 will arrive at the counter after a delay of one time unit during which the "0" in the register will be shifted one place to the right. The "1" output lead of the counter will register "1" in the shift register. Readout leads 4, 5, and 6 carry altogether two "ones," which will register a "0" in the shift register and send one "carry" to the input of the counter. This carry will arrive together with the "1" on readout wire 7 of the group 7 and 8, the counter will count two, register a "0" in the shift register and send one carry to the input of the counter. Since readout lead 9 carries a "0," the counter will count the carry only and register "1" in the shift register, thus completing a multiplication which consists of considerably less steps than the conventional multiplier.

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[1] Patent applied for by the author and D. Alroy.

ear-Zone Power Transmission ormulas*

In his paper[1] the author gives some results of work on energy transmission from a nsmitter to a receiver, previously published by me in a more general statement.

The essential results I obtained can be mmarized as follows:

Let $\overline{E}_1\overline{H}_1$ be the complex electromagnetic ld existing when unit power normalized ave is radiated by transmitter antenna (A). et $\overline{E}_2\overline{H}_2$ be the complex field existing when nit power is radiated by receiver antenna, 3). The receiver antenna is linked to the tector by a transmission line matched at ch end. The field in this receiver transmision line when unit power is radiated by (A) the field of normalized wave propagating om antenna to the detector multiplied by a mplex number $\overline{T}_{12}=T_{12}e^{i\theta}$, which is the ansmission coefficient from (A) to (B). T_{12}^2 is the received power when a normalized ave is transmitted, θ is the phase of the reived wave. In the same way, the transmision coefficient from (B) to (A) can be ded.

I have shown that if S_2 is a surface imediately close to the receiver,

$$\overline{T}_{12}=\frac{1}{4}\int_{S_2}(\overline{E}_1\times\overline{H}_2+\overline{H}_1\times\overline{E}_2)\cdot ds. \quad (1)$$

S_1 is a surface close to the transmitter

$$\overline{T}_{21}=\frac{1}{4}\int_{S_1}(\overline{E}_2\times\overline{H}_1+\overline{H}_2\times\overline{E}_1)\cdot ds. \quad (2)$$

If $\bar{\bar{\epsilon}}$ and $\bar{\bar{\omega}}$ are symmetric

$$\nabla\cdot(\overline{E}_1\times\overline{H}_2+\overline{H}_1\times\overline{E}_2)=0. \quad (3)$$

Therefore, in this case,

$$\overline{T}_{12}=\overline{T}_{21}=\frac{1}{4}\int_S(\overline{E}_1\times\overline{H}_2+\overline{H}_1\times\overline{E}_2)ds, \quad (4)$$

S being any surface surrounding completely b without surrounding (A).

The preceding relationships are of great interest because the medium is not necessarily homogeneous as it is in the Kirchhoff and Kottler relationships. Eqs. (1) and (2) assume no restriction on the medium between (A) and (B). Eq. (4) allows heterogeneity of any kind if $\bar{\bar{\epsilon}}$ and $\bar{\bar{\omega}}$ are symmetrical. Huyghen's principle is a particular case of these very general and rigorous relationships.

Two important cases are encountered for which $\bar{\bar{\epsilon}}$ and $\bar{\bar{\omega}}$ are not symmetrical; therefore, $\overline{T}_{12}\neq\overline{T}_{21}$.

In electron tubes it is found that

$$\overline{T}_{12}-\overline{T}_{21}=\int_v(\overline{E}_1\bar{i}_2-\overline{E}_2\bar{i}_1)dv,$$

V being the volume between (A) and (B), $\bar{i}_1$ and $\bar{i}_2$ being the currents produced by normalized waves transmitted by (A) and (B).

In the ferrite case,

$$\overline{T}_{12}-\overline{T}_{21}=\frac{K\omega v_0}{2}\int_v\overline{H}o\cdot(\overline{H}_1\times\overline{H}_2)dv,$$

$\overline{H}o$ being the unit vector in the direction of the applied magnetic field. This last relationship has also been found by Heller of the Lincoln Laboratory, Massachusetts Institute of Technology.

I have found relationships giving the variation of $\overline{T}$ with respect to frequency. If $\bar{\bar{\epsilon}}$ and $\bar{\bar{\omega}}$ are symmetrical, this relationship has a simple form:

$$\frac{\delta\overline{T}}{\delta\omega}=\frac{1}{2}\int_v(\overline{E}_1\cdot\bar{\bar{\epsilon}}\cdot\overline{E}_2-\overline{H}_1\cdot\bar{\bar{\omega}}\cdot\overline{H}_2)dv.$$

I used (4) and made the first demonstration in the early months of 1956, in the case of a surface wave problem. Reports have been given to the Air Research and Development Center of Cambridge, Mass. (AF Contracts Nos. 61-514-933 and 61-514-1149), which sponsored this work, in July, 1956; November, 1956; May, 1957; and November, 1957. I gave a speech on this topic, in September, 1956, at the "Colloque international sur la propagation," in Paris, France. A paper summarizing the speech has been given to *Onde Electrique* in June, 1957, and published in December, 1957. Other speeches have been given in October, 1957, at the "Congrès international des circuits et antennes hyperfréquences," and in October, 1958, at the Meeting on Propagation, in Liege, Belgium. On this same topic, a paper entitled "Compte rendu à l'Académie des Sciences" was published on August 12, 1957.

These theorems can be considered very general ones in physics. They can be extended to other fields than electromagnetic theory; I applied them to wave mechanics and fluid mechanics. In electromagnetics I have used them to develop a theory of surface wave and propagation problems, particularly concerning tropospheric scatter propagation. A synthesis of all the work will be published in the *Annales de Radioeléctricité.*

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* Received by the IRE, February 10, 1959.

[1] M.-K. Hu, "Near-zone power transmission formulas," 1958 IRE National Convention Record, vol. 6, Pt. 8, pp. 128–135.

Contributors

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❖

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❖

Robert W. Berry was born in Atlanta, Ga., on October 27, 1928. In 1950, he received the B.S. degree in chemistry with high honors from The Clemson Agricultural College, Clemson, S. C. He received the Ph.D. degree in chemistry from Michigan State University, East Lansing, in 1956.

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From 1951 to 1953, he served as a lieutenant in the Chemical Corps, with duties as a physical chemist at the Chemical and Radiological Laboratories. He joined the staff of the Bell Telephone Laboratories, Murray Hill, N. J., in 1956 as a member of the technical staff in the component development department.

Dr. Berry is a member of the American Chemical Society, Sigma Xi, Sigma Pi Sigma, and Phi Kappa Phi.

❖

E. Folke Bolinder (A'50–M'55) was born at Uppsala, Sweden, on August 11, 1922. He received the Civilingenjoer degree in electrical engineering in 1945 and the degree of Teknologie Licentiat in 1954, both at the Royal Institute of Technology, Stockholm.

After a year of military service as a special engineer in the Swedish Air Force, where he worked on UHF antennas and cir-

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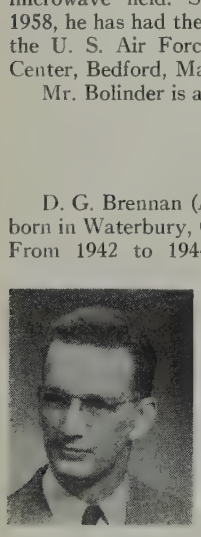
❖

D. G. Brennan (A'48–M'51–SM'57) was born in Waterbury, Conn., on April 9, 1926. From 1942 to 1944, he was engaged in broadcast and communication system engineering and from 1944 to 1947, he was with the U. S. Army Signal Corps, principally as Chief of Communications, Southern Islands Command, Southwest Pacific Theater. From 1947 to 1949, he was chief engineer of Radio Station WWCO, Waterbury, Conn. In 1949–1951, he was an instructor at the Ward School of Electronics of the University of Hartford, Conn. He has been at the Massachusetts Institute of Technology, Cambridge, Mass., since 1951, and the M.I.T. Lincoln Laboratory since 1953, where he has conducted ionosphere research, electronic circuit and system design, and mathematical research. He is currently engaged in basic research in mathematics, and some occasional teaching in the M.I.T. Department of Mathematics, while continuing his association with the Lincoln Laboratory. He was a Gerard Swope Fellow during the 1955–1956 academic year.



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James F. Gibbons was born on September 19, 1931, in Leavenworth, Kan. In 1953, he received the B.S. degree in electrical engineering from Northwestern University, Evanston, Ill., where he was a co-winner of the Eshback Award for the outstanding engineering graduate. He received the M.S. degree in electrical engineering in 1954, and the Ph.D. degree in 1956 at Stanford University, Stanford, Calif. He was a National Science Foundation Fellow from 1953–1955 and an RCA Fellow in Electronics in 1956. After completion of his graduate studies, he was awarded a Fulbright Fellowship to Cambridge University, Cambridge, Eng., for the year 1956–57, where he studied nuclear magnetic resonance.

J. F. Gibbons

Since 1957, he has been an assistant professor of electrical engineering at Stanford University, his major interest being in solid-state devices. During the year 1957–58, he also worked half-time with the Shockley Transistor Corporation, where he is presently a consultant.

Dr. Gibbons is a member of Phi Eta Sigma, Pi Mu Epsilon, Eta Kappa Nu, Tau Beta Pi, Sigma Xi, and an honorary member of the Western Society of Professional Engineers.

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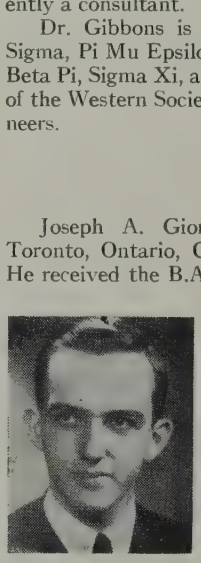
Joseph A. Giordmaine was born in Toronto, Ontario, Can. on April 10, 1933. He received the B.A. degree in physics and chemistry at the University of Toronto in 1955, and the A.M. degree in physics at Columbia University, New York, N. Y., in 1957.



J. A. Giordmaine

Since 1955, he has been research assistant and Esso Fellow at the Columbia Radiation Laboratory, working in the fields of solid-state and maser physics, and radioastronomy.

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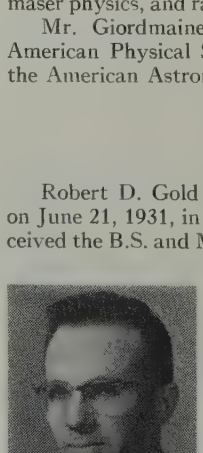
Robert D. Gold (A'54–M'58) was born on June 21, 1931, in Brooklyn, N. Y. He received the B.S. and M.S. degrees in electrical engineering from the City College of New York, N. Y., in 1953 and Cornell University, Ithaca, N. Y., in 1957, respectively.



R. D. Gold

He spent three months with the RCA Victor Division before entering the U. S. Army in 1953. Assigned to the Electronic Warfare Department under the Scientific and Professional Personnel Program, he worked on feasibility studies of radar countermeasure systems. He joined the RCA Laboratories, Princeton, N. J., in 1957, where he has worked on television circuits and kinescopes, and in the field of semiconductor devices. He is currently a lecturer in electrical engineering at the City College of New York.

Mr. Gold is a member of Tau Beta Pi and Eta Kappa Nu.

❖

Douglas J. Hamilton (A'53) was born in Canton, Ohio, on December 6, 1930. He attended the College of Wooster, Wooster, Ohio. He received the B.S. degree from Case Institute of Technology, Cleveland, Ohio, in 1953 and the M.S. degree from the University of California, Los Angeles, in 1956.

D. J. Hamilton

From 1953 to 1957, he was employed by Hughes Aircraft Co., Culver City, Calif., where he was engaged in the development of transistor circuitry for airborn digital computers. In 1957, he joined the General Electric Company Computer Laboratory, Palo Alto, Calif., where he was engaged in the development of transistor circuitry for magnetic core and magnetic drum memories. Since 1958, he has been a research assistant at Stanford Electronics Labs., Stanford University, Stanford, Calif., where he is studying for the doctorate.

Mr. Hamilton is a member of Eta Kappa Nu, Tau Beta Pi, and an associate member of Sigma Xi.

❖

Cornell H. Mayer (M'47) was born in Ossian, Ia., on December 10, 1921. He received the B.S. degree from the State University of Iowa, Iowa City, in 1943, and the M.S. degree in electrical engineering from the University of Maryland, College Park, in 1951. From 1943 to 1948, he did design and development work on microwave receivers and antennas at the U. S. Naval Research Laboratory in Washington, D. C., and, since 1948, has been engaged in research in radio astronomy.

C. H. Mayer

Mr. Mayer is a member of the American Astronomical Society, URSI, and the Scientific Research Society of America.

❖

H. T. McAleer (S'51–A'54–M'59) was born in Boston, Mass., on August 17, 1930. He received the B.S. and M.S. degrees, in

ctrical engineering, in 1953, from the Mas-chusetts Institute of Technology, Cam-dge, Mass.

H. T. McAleer

In 1953, he joined the General Radio Company in Cambridge, Mass., as a development engineer in the Signal Generator Group, concerned with the problems of standard frequency generation in the UHF range. From 1954 to 1956, he served as an officer in the U. S. Army gnal Corps, at the Signal Corps Engineering Laboratories in Fort Monmouth, N. J. is work there consisted of research and de-lopment on crystal filters, and frequency easurement and synthesis equipment. In 56, he rejoined the General Radio Com-ny as a development engineer in the Fre-ency Control Group, concerned with pulse d digital equipment and the general prob-ms of frequency control.

Mr. McAleer is a member of Eta Kappa u, Tau Beta Pi, and Sigma Xi.

❖

Louis Pensak (A'42–SM'47) was born June 16, 1911, in New York, N. Y. e received the B.S. degree from Long Island University, Brooklyn, N.Y., in 1932 and spent the next year as a graduate assistant at the University of Pittsburgh, Pittsburgh, Pa. In 1936, he received the M.S. degree in physics from New York University, N. Y.

L. Pensak

He joined the cathode-ray tube de-lopment section of RCA in 1937 and in 40, was transferred to the Research De-artment of RCA Victor Division. Since 41, he has been with RCA Laboratories, rinceton, N. J., where he has worked on inescopes and storage tubes and solid state evices.

Mr. Pensak is a member of Sigma Xi.

❖

John R. Pierce (S'35–A'38–SM'46–F'48), r a photograph and biography, please see age 455 of the March, 1959 issue of Pro-EEDINGS.

❖

Charles Ferencz Pulvari (SM'54) was rn in Karlsbad, Austria-Hungary in July, 07. He received the diploma in electrical d mechanical engineering at the Uni-rsity of Technical Sciences in Budapest, ungary.

After graduation, he was associated with e Research Laboratories of the Telephone lanufacturing Company in Budapest for ree years. He then joined the Hungarian adio and Communications Corporation as chief engineer and later became technical managing director. In 1937, he became a consultant on television for Scophoney, Limited, London. After the Second World War, he organized his own research laboratory in the switching and communications field and began research in solid-state physics. He came to the United States in 1949 and joined George Washington University, Washington, D. C., where he pursued research on electro-static information storage devices. In 1951, he became a member of the staff of the Catholic University of America, Washington, D. C., and is presently a professor of electrical engineering and head of the Solid-State Research Laboratory. He has contributed to the development of ferroelectric materials and their various applications and holds numerous U. S. patents.

C. F. Pulvari

Prof. Pulvari is a member of Sigma Xi.

❖

William Shockley (SM'51–F'55), for a photograph and biography, please see page 1314 of June, 1958 issue of Proceedings.

❖

Doris J. Sloan was born in Summit, N. J., on January 9, 1936. In 1957, she received the B.S. degree in chemistry from Mount Holyoke College, South Hadley, Mass. She then came to the Bell Telephone Laboratories, Murray Hill, N. J., where, as a member of the component development department, she has worked on the development of printed capacitors.

D. J. Sloan

Miss Sloan is a member of The American Chemical Society.

❖

Martin C. Steele was born on December 25, 1919, in New York, N. Y. He received the B.S. degree in chemical engineering in 1940 from Cooper Union Institute of Technology, New York, N. Y. He received the M.S. and Ph.D. degrees in physics in 1949 and 1952, respectively, from the University of Maryland, College Park.

M. C. Steele

During the years 1942 through 1946, he was in the U. S. Army. After his discharge, he worked at the Naval Research Laboratory, Washington, D. C., as a research physicist in the field of solid state physics. His major interests there were in superconductivity and magnetic properties of metals at low temperatures. He was the head of the Cryomagnetic Research Section at the Naval Research Laboratory. Since 1955, he has been at RCA Laboratories, Princeton, N. J., doing research in semiconductor physics.

Dr. Steele is a member of Sigma Xi and the American Physical Society.

❖

Charles H. Townes (SM'58) was born in Greenville, S. C., on July 28, 1915. He received the B.A. degree in modern languages and the B.S. degree in physics from Furman University, Greenville, in 1935, the M.A. degree in physics from Duke University, Durham, N. C., in 1937, and the Ph.D. degree in physics from the California Institute of Technology, Pasadena, in 1939.

C. H. Townes

From 1939 to 1947, he was a member of the technical staff of the Bell Telephone Laboratories. At Columbia University, New York, N. Y., he was an associate professor of physics from 1948 to 1950, Director of the Columbia Radiation Laboratory from 1950 to 1952, and Chairman of the Physics Department from 1952 to 1955. Since 1950, he has been a professor of physics.

His research has been in the fields of microwave spectroscopy, hyperfine effects, nuclear moments and structure, molecular structure, atomic time standards, electronic devices, masers, and radioastronomy.

Dr. Townes is a member of the Scientific Advisory Board of the Air Force, the Council of the American Physical Society, the National Academy of Sciences, and the American Academy of Arts and Sciences. He was the recipient of the Research Corporation Annual Award for 1958 and co-recipient of the Morris Liebmann Memorial Prize of the IRE for 1959.

❖

Jerald A. Weiss was born in Cleveland, Ohio, on June 9, 1922. After some undergraduate training and industrial work in chemistry, he received the B.A. and M.A. degrees in 1949, and the Ph.D. degree in physics in 1953 at Ohio State University, Columbus.

J. A. Weiss

He joined the faculty of the University of Wyoming, Laramie, in 1949, as instructor in mathematics, and in 1951 returned to Ohio State as a graduate student. In 1953, he joined the Bell Telephone Laboratories, Murray Hill, N. J., in work relating to microwave magnetic materials and devices.

Dr. Weiss is a member of the American Physical Society, the Mathematical Association of America, Phi Beta Kappa, and Sigma Xi.

Scanning the Transactions

Information theory unquestionably is regarded as one of the great conceptual advances of the radio engineering field. At the same time, quite a few authorities have expressed doubt from time to time as to whether much of the basic work being done in this field is leading to any worthwhile results. In a recent TRANSACTIONS editorial, a well-informed "outsider" from the field of mathematics had these provocative observations to make on this fundamental question:

"In spite of all the suggestive work by Wiener, Shannon, and their successors, the main thing that strikes an outsider is that there are so few theoretical results. In fact almost every time a writer proves an assertion connecting the capacity of a channel with the entropy of a source, his paper P_n is succeeded by a paper P_{n+1} which, instead of generalizing or extending the results of P_n, is devoted to pointing out and correcting some defect or insufficiency in it. The paper P_{n+1}, in its turn, receives the same harsh treatment, and so on. Moreover, in this presumably convergent process of purging and purifying, the theorems become more and more attenuated and inapplicable as their hypotheses become more restrictive.

"Even more extraordinary is the fact that this process of organizing what seems to be the very basis of the subject seems to have no effect whatever on its applications! Can it be that the existence of a mathematical basis is irrelevant, and that the basic principle is the very idea that there is a context in which the word 'information' is accepted by general agreement and used in an intuitive way, and that no more is needed?" (J. L. Doob, IRE TRANS. ON INFORMATION THEORY, March, 1959.)

Public telephones on airplanes may soon become an established service for air travelers. Two Bell System operating companies have been conducting commercial trials since September, 1957, with very satisfactory results. These trials are using 15-watt 450-mc FM airborne transmitters, with interconnection to the regular telephone network being provided by two land base stations, one in Chicago and the other near Detroit. Thus, progress in the telephone system has, so to speak, reached new heights. (R. V. Crawford, "Transmission tests on a trial system of telephone service for aircraft," IRE TRANS. ON VEHICULAR COMMUNICATIONS, April, 1959.)

Body-snatching. The increased demand for scientists and engineers over the past few years has made the technical recruiter a frequent and familiar sight on college campuses and at technical meetings throughout the country. He has also become a frequent and familiar target for criticism in the press. *Time* magazine once summed up an engineering convention with the caustic caption, "Recruiting? Forbidden. Piracy? Okay." More recently, the *New York Times*, perhaps moved by the sudden influx of employment ads, took notice of the opening of another meeting with the words, "The annual body-snatching of electronics engineers . . . began yesterday."—a salvo that was quoted a week later on the editorial page of *The Nation*. The prevailing impression seems to be that recruiters live only by the law of the jungle and that engineers are either helpless prey or, at least, can always be had for a price. Midst all these slings and arrows it is, therefore, a refreshing and welcome change to find recruiting spoken of, for once, as a respectable pursuit carried on by intelligent, responsible people. It is also reassuring to find that a recent survey of 20,000 engineers and scientists reveals that of 15 factors contributing to job satisfaction, they placed the following at the top of the list, in order of importance:

1) Interest potential of work.
2) Integrity of management.
3) Opportunity to discover and do creative work.
4) Opportunity to move up in the organization.
5) Caliber of supervision.
6) Living conditions.
7) Pay.

Evidently, engineers and scientists are not as materialistic as some would have us believe, and job satisfaction and professionalism are still strong motivating factors. (J. Kurshan, "Recruiting the technically creative—a dual responsibility," IRE TRANS. ON ENGINEERING MANAGEMENT, March, 1959.)

Should we say "data" or "information"? Probably most of us can safely use the two words interchangeably. There is, however, a distinction in meaning which becomes important to preserve when speaking of data-handling or information-processing systems. "Data" are the raw material from which "information" is derived. The differentiation is important only when there exists a desire to know *specific* facts, in contrast to a situation where any kind of facts are interesting as long as it is news. Thus, we can say that communicated facts are 1) "data," if they are not called for and do not contain any "news" value for the receiver at that time, 2) "news," if it is not called for but arouses an interest, or 3) "information," if it has been called for and increases the knowledge of the interrogator at that time. (E. A. Keller, "Data or information," IRE TRANS. ON INDUSTRIAL ELECTRONICS, April, 1959.)

Communication between machines, and between men and machines, has grown in volume almost to the point where it exceeds the amount of communication traffic between humans, so rapid have been the strides in digital data translation and transmission techniques. The most recent development in this fast-moving area is a transistorized special purpose computer, called MAUDE, that can decode hand-sent Morse code messages. MAUDE has thus far successfully decoded between 90 per cent and 95 per cent of the messages sent her by 184 operators, and its developers feel she can be a practical addition for a site with heavy traffic. Moreover, MAUDE has shed light on the interesting question of the extent to which a decoder (either a man or a machine) needs to know the language being encoded, in addition to knowing the code itself. It was found that MAUDE, even though she knows Morse code, would need to be taught more sophisticated language rules, including a word vocabulary, before she could be as good a decoder as a man. (B. Gold, "Machine recognition of hand-sent Morse code," IRE TRANS. ON INFORMATION THEORY, March, 1959.)

A new twist in memory devices makes use of a magnetic effect first observed a century ago involving twisted magnetic rods. Although the new element, appropriately called the "Twister," is still in the experimental stage, it has shown great potentialities for the future. In fact, it is expected that the Twister will someday probably replace many magnetic core and drum types of memories in computers and electronic switching systems where a rapid-access, high-capacity memory is necessary. The Twister makes use of the fact that a magnetic rod or wire under a mechanical torsion will produce a voltage between its ends when it is magnetized by a field acting along its longitudinal axis. It is interesting to note that in 100 years this is probably the first important use that has been found for this phenomenon. (D. A. Ellerbruck, "A new memory device—the Twister," IRE TRANS. ON COMPONENT PARTS, March, 1959.)

Graduate degrees in engineering were first awarded in the U. S. in 1873. Since then, graduate student enrollments have greatly increased, particularly in the last two decades, so that today well over 100 institutions annually award more than 1000 advanced degrees in electrical engineering alone. During this period the conditions under which graduate work is given have undergone considerable change. The Master's degree, for instance, which once was exclusively a research degree, has had to be modified to include advanced design as a proper subject for a thesis, in order to accommodate the greatly enlarged number of students pursuing this degree. In fact, some institutions today do not even require a thesis for a Master's degree. The advent of government and industry-sponsored research in universities has had a pronounced effect on graduate study programs, as have the off-campus graduate programs which an increasing number of companies now offer their technical employees. These and many other aspects of present-day graduate study were the subject of a unique and fruitful conference of electrical engineering educators, held last summer by Syracuse University and the IRE Professional Group on Education. The meeting gave educators an unusual opportunity to clarify their understanding of these highly important matters, and has given the PGE an opportunity to publish a record of their discussions for the further enlightenment and benefit of our profession. (Sagamore Conference on Electrical Engineering Education, IRE TRANS. ON EDUCATION, April, 1959.)

Electroluminescence, despite being a subject of only fairly recent interest, has been written about extensively in the technical literature. Because of both this recent interest and the voluminous literature, a recent bibliography on the subject is worthy of special note. The number of references contained in it is a surprising 720, attesting to the thoroughness with which this valuable document was compiled. (H. F. Ivey, "Bibliography on electroluminescence and related topics, "IRE TRANS. ON ELECTRON DEVICES, April, 1959.)

Report of the Secretary—1958

TO THE BOARD OF DIRECTORS
THE INSTITUTE OF RADIO ENGINEERS, INC.

Gentlemen:

Again comes the Secretary's Report for the year 1958. General growth continues, membership being up from 64,773 at the end of 1957 to 71,361. (See Fig. 1 and Table I.) The percentage of voting members to the total has risen. In fact, five years ago 28% of the total were voting members whereas now they number 59%. The number of Students has gone up 11%. Over the past five years Students have risen in number from 5556 to 14,961.

Six new Sections bring the total number to 100.

Your Secretary notes with satisfaction the 18% growth of the IRE publications as to editorial pages, the improved format of the PROCEEDINGS, the continued widespread activities of the Technical Department, the increases in size and activities of the Professional Groups, the larger Annual Convention, and the bigger figures displayed on the financial statements.

Respectfully submitted,

Haraden Pratt

Haraden Pratt
Secretary

January 31, 1959

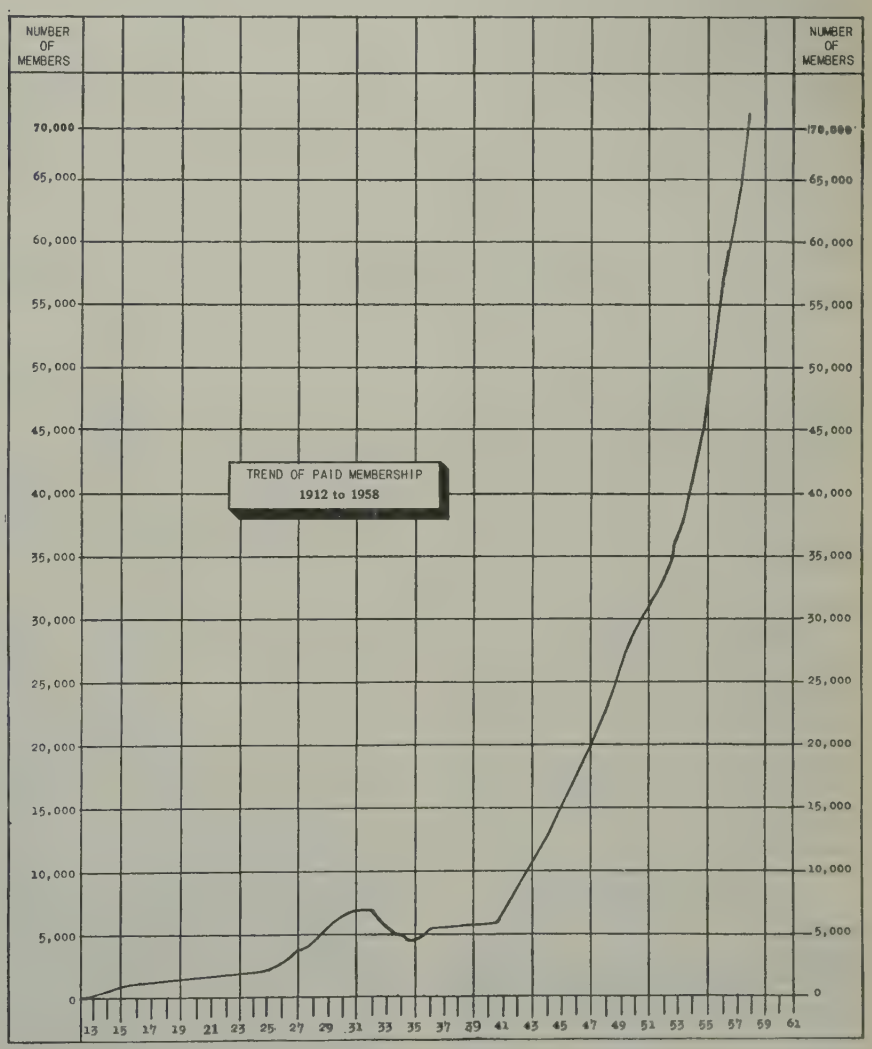


Fig. 1

Fiscal

A condensed summary of income and expenses for 1958 is shown in Table II, and a balance sheet in Table III.

TABLE I

COMPARISON OF TOTAL MEMBERSHIP DISTRIBUTION BY GRADES, 1956–1958

Grade	As of Dec. 31, 1958		As of Dec. 31, 1957		As of Dec. 31, 1956	
	Number	% of Total	Number	% of Total	Number	% of Total
Fellow	770	1.1	700	1.1	635	1.1
Senior Member	8,536	12.0	7,685	11.9	6,486	11.6
Member	32,373	45.4	26,115	40.3	19,110	34.6
Associate	14,721‡	20.6	16,827†	25.9	18,879*	34.0
Student	14,961	20.9	13,446	20.8	10,384	18.7
TOTALS	71,361		64,773		55,494	

* Includes 388 Voting Associates.
† Includes 352 Voting Associates.
‡ Includes 330 Voting Associates.

TABLE II

SUMMARY OF INCOME AND EXPENSE, 1958

Income		
Advertising	$1,243,535	
Member Dues and Convention	1,395,384	
Subscriptions	179,634	
Sales Items: Binders, Emblems, etc.	167,195	
Investment Income	39,181	
Miscellaneous Income	1,783	
TOTAL INCOME		$3,026,712
Expense		
PROCEEDINGS Editorial Pages	$ 486,036	
Advertising Pages	626,080	
Directory	249,359	
Section Rebates	71,820	
Student Program	105,292	
Professional Group Expense	182,407	
Sales Items	122,499	
General Operations	501,520	
Convention Cost	412,779	
TOTAL EXPENSE		$2,757,792
Reserve for Future Operations—Gross		$ 268,920
Depreciation		22,344
Reserve for Future Operations—Net		$ 246,576

TABLE III

BALANCE SHEET—DECEMBER 31, 1958

Assets		
Cash and Accounts Receivable	$ 645,997	
Inventory	34,244	
TOTAL CURRENT ASSETS		$ 680,241
Investments at Cost	1,490,478	
Building and Land at Cost	912,317	
Furniture and Fixtures at Cost	241,989	
Other Assets	77,786	
TOTAL		2,722,570
TOTAL ASSETS		$3,402,811
Liabilities and Surplus		
Accounts Payable	$ 72,519	
TOTAL CURRENT LIABILITIES		$ 72,519
Deferred Income	879,073	
Professional Group Funds on Deposit	217,822	1,096,895
TOTAL LIABILITIES		1,169,414
Reserve for Depreciation		81,112
Surplus Donated	595,287	
Surplus	1,556,998	
TOTAL SURPLUS		2,152,285
TOTAL LIABILITIES AND SURPLUS		$3,402,811

TABLE IV

VOLUME OF PROCEEDINGS PAGES

	1958	1957	1956	1955
Editorial	2199	1868	1996	2060
Advertising	2169	2700	2800	2372
TOTAL	4368	4568	4796	3956

TABLE V

VOLUME OF TRANSACTIONS PAGES

	1958	1957	1956	1955
Groups Publishing	26	24	23	21
No. of Issues	81	75	69	56
No. of Pages	5388	5372	5044	3504

Editorial Department

PROCEEDINGS OF THE IRE

Several important changes were adopted by the Editorial Board during 1958 in order to increase the value and utility of the PROCEEDINGS to the membership. A new monthly feature, called "Scanning the Transactions," was inaugurated with the February issue in order to single out and interpret for the general reader some of the significant or unusual work that is reported in IRE publications he may not normally see, *i.e.*, the TRANSACTIONS, the NATIONAL and WESCON CONVENTION RECORDS, and the STUDENT QUARTERLY. In April the table of contents was expanded to two pages and transferred from the editorial section to the front of the magazine so that it may be found more readily. At the same time the IRE News and Notes Section, because it is not of permanent reference value, was moved to the front portion of the advertising section.

In addition to improvements in format and content, the number of editorial pages was increased 18% over the previous year, reaching an all-time high of 2199 pages, as shown in Table IV and Fig. 2. At the same time the over-all total for all IRE publications reached a new high of 119 issues totaling 15,140 pages.

The increase in PROCEEDINGS editorial output was due primarily to the appearance of a special issue on Radio Astronomy in January, another on Transistors in June, timed to coincide with the tenth anniversary of the transistor, and a special series of reports in July on the URSI Twelfth General Assembly. In addition, the "Correspondence" section continued to expand, with 180 letters to the Editor being published during the year as compared with 146 the previous year.

The volume of material reviewed for PROCEEDINGS remained about the same as the previous year. A total of 294 papers comprising 2195 pages were considered. Of these, 31% were accepted, 35% were referred to the TRANSACTIONS for publication consideration, and 34% were rejected. The number of papers published, 183, was substantially larger than the 1957 total of 130. Seven IRE Standards also appeared during the year.

TRANSACTIONS

The year 1958 saw the TRANSACTIONS output of the Professional Groups continue to increase, as shown in Fig. 2 and Table V. The total number of papers and letters published, 799, represented half of the total number published in all IRE publications during the year (1610). The number of Groups employing letterpress printing increased to 19, and the proportion of pages printed by letterpress increased from 66% to 80%.

IRE CONVENTION RECORDS

The practice of publishing CONVENTION RECORDS for the National and WESCON

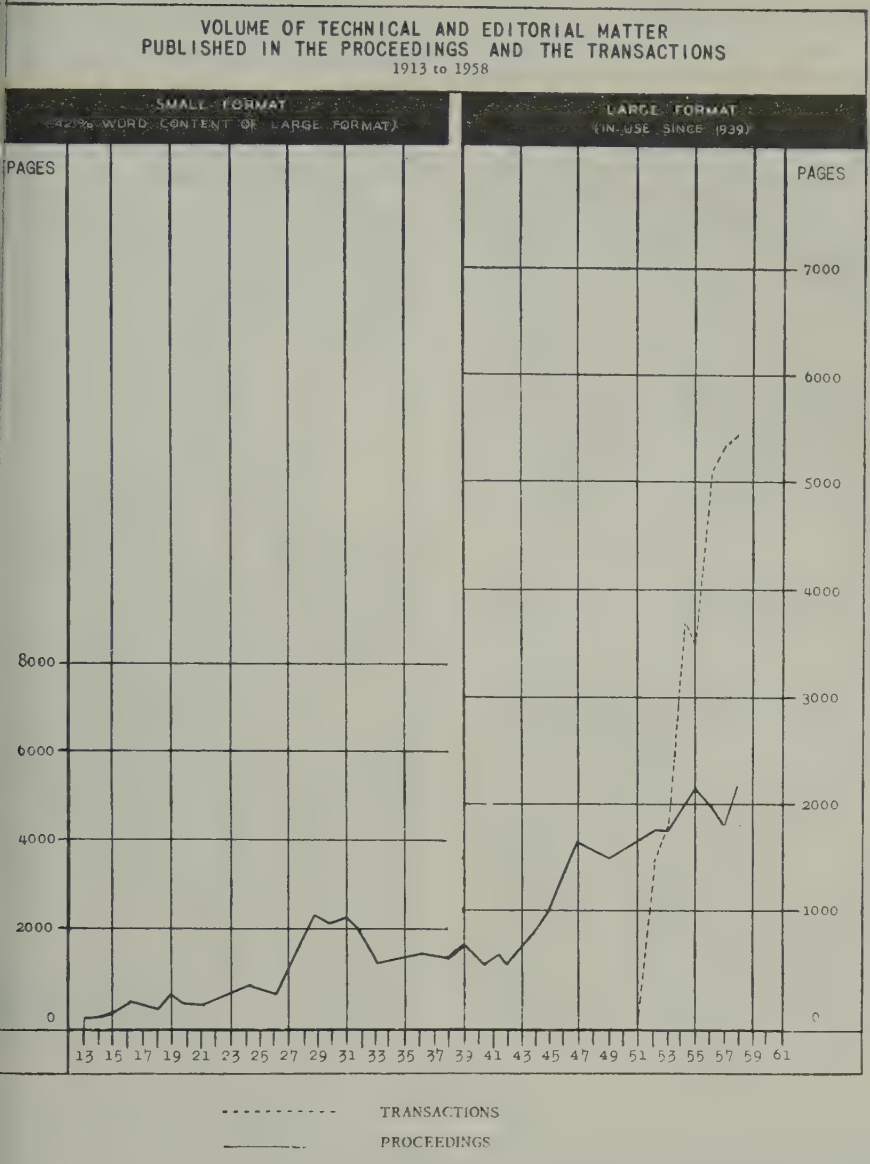


Fig. 2

Conventions was continued. The 1958 IRE National Convention Record, containing 252 papers and 15 abstracts totaling 2144 pages, was issued in ten parts. The IRE WESCON Convention Record contained 180 papers and 14 abstracts totaling 1576 pages, and was issued in nine parts.

IRE Student Quarterly

Four issues, totaling 208 pages, were sent free to IRE student members during the year. In addition, approximately 20,000 free copies of the September issue were distributed to all non-IRE junior and senior electrical engineering students.

IRE Directory

The 1959 IRE Directory was published in November, containing 1152 pages including covers, of which 516 were membership listings and information and 636 were advertisements and listings of manufacturers and products.

Conference Publications

The *Proceedings of the 1957 Eastern Joint Computer Conference*, sponsored jointly by the IRE, AIEE and Association for Computing Machinery, was published by the IRE Editorial Department in June, 1958. The issue contained 264 pages.

Technical Activities

Technical Committees

During 1958 these groups held 262 meetings of which 234 were held at IRE Headquarters and 28 throughout the nation.

Seven Standards, having been approved by the Standards Committee and the IRE Board of Directors, were published in the Proceedings in 1958, and reprints are now available to the public.

In addition an Index to IRE Standards on Definitions of Terms, 1942–1957 was published in the February Proceedings.

IRE is directly represented on 33 Committees of the American Standards Association and sponsors three: the ASA Sectional Committee on Radio and Electronic Equipment, C16; the ASA Sectional Committee on Sound Recording, Z57; and the ASA Sectional Committee on Nuclear Instrumentation, N3. One IRE Standard received approval of the American Standards Association as an American Standard in 1958, and is now available overseas through the International Standards Organization.

IRE Technical Committees actively participated in international standardization in 1958 by reviewing and preparing comments on documents for the United States National Committee of the International Electrotechnical Commission.

Appointed IRE Delegates on Other Bodies

The IRE appointed delegates to a number of other bodies for the one-year period —May 1, 1958 to April 30, 1959 (as listed on page 44A of the October, 1958 issue of Proceedings).

The Annual Spring Meeting of the International Scientific Radio Union (URSI) was held on April 24, 25, and 26, 1958, in Washington, D. C. The Fall meeting was held on October 21 and 22, 1958, in University Park, Pennsylvania. The XIIth General Assembly of URSI was held on August 22 through September 5, 1957, in Boulder, Colorado. The XIIIth General Assembly of URSI will be held on September 5 through 15, 1960, at the University College of the University of London, London, England.

During 1958, the Eexecutive Committee of the U. S. Preparatory Committee of the International Radio Consultative Committee (CCIR) held six meetings. At these meetings, the representatives of the fourteen Study Groups summarized and reported on their activities. Numerous responses to the questions under review by the Study Groups have been received in IRE during 1958. Lists of all material received from these organizations were distributed quarterly to the Chairmen of IRE Technical Committees and Professional Groups, as well as to The Joint Technical Advisory Committee.

In October, 1958, the Executive Committee of the CCIR established a working committee, called "Government-Industry Arrangements Committee" to prepare ways and means and to administer the CCIR Ninth Plenary Assembly. This will be held at the Hotel Biltmore, Los Angeles, California, April 1 through 29, 1959. Two meetings have been held to date and the committee structure is being formed.

In June, 1958, the Department of State organized a committee to prepare U. S. Proposals for the International Telecommunication Union Plenipotentiary Conference (PC/PC to be held in Geneva in October, 1959). At present two Ad Hoc Committees have been established, one will deal with the administration of ITU funds and the other concerns proposals to amend the Radio, Telegraph, and Telephone Regulations between International Conferences. Several meetings have been held to date.

The Joint Technical Advisory Committee

The Joint Technical Advisory Committee held a total of eight meetings for the period July 1, 1957 through June 30, 1958. A Tenth Anniversary dinner was held in May, 1958.

Volume XV, the cumulative Annual Report of the JTAC proceedings was published in 1958. This includes in Section I: Official Correspondence between the Federal Communications Commission and The Joint Technical Advisory Committee (IRE-EIA). Also included were other items of correspondence pertinent to the activities of the JTAC. Section II of the Report contained approved Minutes of Meetings of The Joint Technical Advisory Committee for the period July 1, 1957 through June 30, 1958.

The JTAC Subcommittee, Cooperative Interference Committees (57.1) was established on January 24, 1957 to enlist the cooperation of the IRE Sections and Professional Groups in the publicizing of the "Cooperative Interference Committees project" of the JTAC. This Subcommittee completed its work assignments and was discharged on July 25, 1957.

The JTAC Subcommittees on the Study of Forward Scatter Propagation, Ionospheric Scatter and Tropospheric Transmission (55.1) are nearing the completion of their work assignments and final reports are expected shortly.

The JTAC Subcommittee on Study of Interference from Arc Welders (54.2) was disbanded in January, 1957. The Federal Communications Commission recently requested a progress report of the current status of the RF Arc Welding Industry. A review reveals that the Joint Industry Commission (NEMA) is filing a petition with the FCC, recommending that the proposed rule making on high frequency arc welders be made permanent, due to an appreciable reduction in the number of interference cases reported to the Commission. As soon as JTAC receives a copy of the petition a summary of JTAC's activities will be submitted to the Commission.

The JTAC Subcommittee on Study of Single Sideband Transmission (56.1) completed a résumé (Single Sideband Analysis) and was discharged on January 16, 1958.

The International Electrotechnical Commission (IEC)

The International Electrotechnical Commission Subcommittee 12-1 on Measurements met in Paris, France from March 24 to 31, 1958. IRE secured the services of a delegate to represent the United States, and the IRE Technical Committees prepared this delegate on all items to be discussed at this meeting.

The annual meeting of the International Electrotechnical Commission was held in Copenhagen, Denmark, July 1 to 4, and in Vasteras and Ludvika, Sweden, July 1 to 5, 1958. IRE did not actively participate in these meetings, since there were no meetings of IEC Technical Committee 12 on Radio Communication, or Technical Subcommittee 12-1 on Measurements scheduled at this time.

A list of all documents and material received in the Office of the IRE Technical Secretary from the IEC was distributed to the Chairmen of all Professional Groups, Technical Committees, and Subcommittees.

Professional Group System

General: There are currently 28 Professional Groups operating actively within the IRE.

Approximately 60% of all IRE members have taken advantage of the Professional Group System which now has a total membership of over 72,000. Included are 5408 Student members of the IRE who have joined the Groups at the special Student member rate of $1.00 annually. Under the newly instituted Affiliate Plan, 279 scientists and medical doctors, whose major interests lie in fields other than electronics, have affiliated with a number of the Professional Groups.

All of the Groups have levied publications fees and their members are receiving the pertinent Group TRANSACTIONS regularly. In addition, a large number of company, university, and public libraries have subscribed to the TRANSACTIONS of all the Groups. There is also a demand for individual Group subscriptions and individual copies of the TRANSACTIONS from outside sources.

Financial and editorial assistance were among the many services rendered by Headquarters to the Groups during 1958. The Office of the Technical Secretary provided administrative services for Group operations, the planning of meetings, advance publicity, and the recording and mailing for all activities, including 882 mailings to Group members during the year.

Symposia: The procurement of papers and actual management of national symposia are entirely in the hands of the Professional Groups. Each of the Groups, with the exception of G-28, sponsored one or more technical meetings during this year, in addition to Technical Sessions at the IRE National Convention, the WESCON, The National Electronics Conference and other joint meetings, for a total of 47 meetings of national import in 1958.

Publications: During the year, 25 Groups published 81 TRANSACTIONS containing 5388 pages. Since publication began in 1951, 392 issues (26,092 pages) have appeared. Full details on Group TRANSACTIONS are included in the Report of the Editorial Department.

Professional Group Chapters: 242 Professional Group Chapters have been organized by Group members in 54 IRE Sections. Chapter growth is continuing at a healthy rate. The Chapters are meeting regularly and sponsoring meetings in the fields of interest of their associated Groups in the various Sections.

Section Activities

We were glad to welcome six new Sections into the IRE during the past year. They are as follows: Anchorage, Colombia, Erie (formerly Subsection), Quebec (formerly Subsection), South Carolina (formerly Charleston Subsection), and Western Michigan.

The total number of Sections is now 100.

The Charleston, Erie and Quebec Subsections became full Sections in the year 1958.

The Subsections of Sections now total 28, the following being formed in 1958: Fairfield County (Connecticut), Merrimack Valley (Boston), and Santa Ana (Los Angeles).

A growing major activity of many Sections and the larger Subsections in recent years is the publication of a local monthly Bulletin to fulfill the need for announcing to the Section members the increasing activities of the Section, including 1) Section meetings, 2) Professional Group Chapter meetings, and 3) information on the local and national level of interest to the Section member.

Forty-nine of the Sections and Subsections are now issuing these monthly publications.

Student Branches

The number of Student Branches formed during 1958 was 17. The total number of Student Branches is now 168, 115 of which operate as joint IRE-AIEE Branches, and 9 as Student Associate Branches.

Following is a list of the Student Branches formed during the year: Academy of Aeronautics, Brigham Young University, Broome Technical Community College, California State Polytechnic College (Kellogg-Voorhis Campus), Capitol Radio Engineering Institute, Catholic University of America, University of Houston (College of Engineering), Houston University (College of Technology), Los Angeles State College of Applied Arts and Sciences, Lowell Technological Institute, Loyola University of Los Angeles, Oregon Technical Institute, Provincial Institute of Technology and Art, Tennessee Agricultural and Industrial State University, University of Western Ontario, and Youngstown University.

It is with deep regret that this office records the death of the following members of the IRE during the year 1958.

Fellows

Barkely, William J. (M'29, SM'43, F'56, L'56)
Gustafson, Gilbert E. (A'27, M'38, F'40)
Hallborg, Henry Emanuel (F'45, L'57)

Senior Members

Arnson, Ludwig (M'33, SM'43)
Burnside, Don G. (A'12, SM'46, L'56)
Campbell, Charles A. (SM'52)
Crom, George Curtis (A'22, M'24, SM'43, L'57)
Daly, George M. (A'44, SM'52)
Donnelly, Clarence P. (SM'57)
Exon, Frank C. (A'38, SM'47)
Fitzsimmons, David P. (SM'51)
Fox, Benjamin (SM'54)
Giguere, Edmour F. (SM'52)
Gretener, Edgar (SM'57)
Hasenberg, Werner (SM'53)
Jacobsen, Lance R. (SM'57)
Johnston, Harry C. (SM'53)
Link, Louis J. (A'30, SM'57)
Lippincott, Donald K. (SM'43)
Metcalf, Herbert E. (M'35, SM'43)
Scott, Milton C., Jr. (A'31, SM'50)
Talmage, Franklin E. (A'41, SM'49)

oulon, Pierre Marie Gabriel (SM'47)
ick, Edwin L. (SM'46)
iegand, Erich P. (SM'56)

Members

rmstrong, Albert B. (A'50, M'55)
osley, Clement T. (S'54, M'57)
runo, Theodore P. (M'54)
uffington, Guy B. (M'58)
reutz, Patrick M. (M'57)
avis, Don L. (M'52)
embinski, Leonard J. (A'49, M'55)
ionne, James H. (S'50, A'52, M'56)
urkee, Chauncey H. (M'49)
ymond, Clifton W. (A'36, M'55)
arley, John M. (A'48, M'54)
asley, Lowry E. (M'47)
lliott, L. W. (A'39, M'55)
mmons, Albert W. (S'48, A'49, M'55)
ountain, Henry F. (A'48, M'55)
rancis, M. Clifford (A'44, M'55)
ould, Roderick (S'55, M'58)
landler, Joseph E. (M'47)
acobs, Herbert, Jr. (S'43, A'47, M'55)
ohnson, Harold S. (M'50)
oyce, Maurice V. (S'51, A'52, M'56)
aplan, Jack (S'44, A'50, M'55)
elly, Joseph M., Jr. (A'43, M'55)
enyon, F. Ralph (A'38, M'55)
ohler, Ernest, Jr. (A'31, M'55)
oziuk, Frank S. (M'56)
yet, Louis F. (M'57)
larsh, Mendole D. (M'53)
IcCoy, John G. (S'49, A'51, M'56)
Morris, Robert (A'46, M'55)
Muller, John S. (A'51, M'56)
Museus, Hjalmer U. (A'47, M'55)
Palmer, Vinson L. (S'39, A'41, M'44)
Paluthe, Wilfred F. S. (S'56, M'57)
Pegram, George B. (A'12, VA'39, M'55, L'47)
Price, Osborne I. (A'43, M'55)
Read, Cyrus T. (A'43, M'55)
Robidoux, Finley T. (A'46, M'55)
Scheck, James A. (M'58)
Seabury, Edwin M. (M'50)
Shubert, H. Neal (A'46, M'55)
Stautner, Paul L. (M'48)
Sykes, Stephen D. (M'55)
Trinkle, Wilmer S. (M'49)
Van Nostrand, Albert W. (S'55, M'57)
Watts, Wilbur E. (M'46)
Wellendorf, Joseph J. (A'36, M'45)
Wiegerinck, Hendrikus T. J. (M'54)
Williams, Robert E. (A'44, M'48)

Voting Associates

Jones, Benjamin F., Jr. (A'39, VA'39)
Lyon, Henry H. (A'14, VA'39)
Waite, Samuel A. (A'22, VA'39)

Associates

Alonso, Carlos J. (A'51)
Barsky, Norton (S'53, A'54)
Becker, Otto F. (A'57)
Benson, William J. (A'56)
Brabec, Rudolph J. (A'57)
Bradish, Walter M. (A'51)
Buck, Harold W. (A'56)
Chenoweth, William G. (A'51)
Crouser, Earl E. (A'53)
Dennison, George L. (A'54)
Driggs, Lee O. (A'44)
Fuchs, George W. (S'50, A'53)
Gnewotta, Milton R. (S'56, A'57)
Grinberg, Eduardo (A'51)
Johnson, William H. (A'55)
Lambert, Gerald M. (S'50, A'53)
Marcinko, Frank C. (A'46)
McMillan, Dayton, N. (A'53)
O'Reilly, Thomas F. (A'56)
Remorenko, Michael S. (A'52)
Roka, Edward G. (A'54)
Ross, Nicholas E. (A'57)
Schwartz, Chris N. (A'55)
Scrimshire, John B. (S'43, A'45)
Stoffel, Lester L. (A'35)
Taylor, Marvin A. (A'56)
Van Allen, John W. (A'52)
Walker, Richard D. (A'53)

Students

De Vries, Ramon A. (S'57)
Larue, Jean (S'57)
Mitchell, Don E. (S'57)
Mooney, Philip L. (S'56)
Neumann, Richard G. (S'56)
Noble, Robert G. (S'57)
Perrone, Gerard T. (S'57)
Shay, Lynn (S'57)
Sullivan, Thomas D. (S'57)

Books

lectrical Engineering Materials, by A. J. Dekker

Published (1959) by Prentice-Hall, Inc., Englewood Cliffs, N. J. 197 pages+4 index pages+ix pages. Illus. 6×9. $8.00.

In this short book, the author undertakes o provide the subject matter for a one-uarter course in those aspects of materials nd their behavior of interest to electrical ngineering students. His approach is to dis-uss the necessary general aspects of atomic nd molecular structure, and from these to ow how the properties and behavior may e explained. This reviewer feels that Dr. Dekker has done a masterful job in the se-ction and presentation of the material in is 200 page book.

In his Preface, Dr. Dekker notes that his xpected audience probably has no back-round in quantum mechanics, except per-aps in a passing manner. For this reason e has used classical or semiclassical models, ften supplemented by arguments based on ore advanced principles, to provide a co-erent picture. In his words, "I feel that the ck of rigor implied by these models is out-eighed by their usefulness in providing the udent with a reasonable amount of insight to the physical mechanisms which under-e the properties of materials."

The book contains seven chapters. Chapter 1, "Atoms and Aggregates of Atoms," provides a general introduction to atomic and molecular nomenclature and properties. Chapter 2, "Dielectric Properties of Insulators in Static Fields," contains an account of the various types of polarization, and their relation to the dielectric properties of materials. Chapter 3, "Behavior of Dielectrics in Alternating Fields," examines the frequency response characteristics of dielectrics. Chapter 4, "Magnetic Properties of Materials," is in two parts, the first of which contains background material; the second section addresses itself to the atomic interpretation of the magnetic properties of materials. Chapter 5, "The Conductivity of Metals," relates the conductivity and its temperature dependence through the free electron gas model, and the electron motion in the periodic lattice structure of matter. Chapter 6, "The Mechanism of Conduction in Semiconductors," provides a discussion of the mechanism underlying the action of semiconductor devices. Chapter 7, "Junction Rectifiers and Transistors," contains a condensation of the important properties of semiconductor devices.

Some readers may perhaps protest the occasional lack of rigorous justification of some developments, or may take issue with Dr. Dekker in occasionally using relations without proof, where the proof may be quite involved. However, if one keeps in mind his stated limited purpose and the student for whom this book has been written, I think that he has succeeded remarkably well.

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Liquid Scintillation Counting, edited by Carlos G. Bell, Jr. and F. Newton Hayes

Published (1958) by the Pergamon Press, 122 E. 55 St., N. Y. 22, N. Y. 292 pages+xi pages. Illus. 6×9¼. $10.00.

This volume is the transcript of a symposium which was held at Northwestern University in August, 1957. The liquid scintillation technique has recently found wide application for quantitative measurement of beta emitting radioisotopes. Hence this conference was held to bring together instrument designers from research laboratories, commercial manufacturers of liquid scintillation apparatus, and a broad spectrum of those who make use of the techniques. Many others who belong to these three categories will welcome this written record. The review

articles and many of the specific papers will be of interest to anyone who may be concerned with the design or use of scintillation equipment. This volume, together with the Scintillation Counter Symposia papers published in the IRE TRANSACTIONS ON NUCLEAR SCIENCE (Vol. NS-5, No. 3, NS-3, No. 4) constitute an excellent basic library on the subject.

There are 35 papers which cover the basic processes involved in liquid scintillators, design of present day laboratory and commercial counting systems, the chemistry required to get the elements of interest from various samples into the scintillating liquid, applications of the technique in different fields (archeology, biology, chemistry, industry, medicine, physics), and some examples of unusual systems such as the antineutrino experiment of Cowan and Reines which used 3600 gallons of liquid scintillator and 110 five-inch photomultiplier tubes.

There is some duplication of material and variation in the quality among the chapters, but the material is well arranged and well presented.

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The Theory and Design of Magnetic Amplifiers, by E. H. Frost-Smith

Published (1959) by John Wiley and Sons, Inc., 440 Fourth Ave., N. Y. 16, N. Y. 443 pages+6 index pages+4 bibliography pages+34 appendix pages +xix pages. Illus. 5½×3½. $12.50.

This is the first book in a new Automation and Control Engineering Series coming from Great Britain. As the author points out in the preface, the aim of the book is to give an account of the theory of magnetic amplifiers and to link the theory with the design in such a way that it will be of value not only to the professional engineer but also to the university student. Dr. Frost-Smith is most likely to attain this goal.

The book opens with an introduction to basic magnetic circuits. The next two chapters deal with the transductor (this term was adopted in Great Britain after the Second World War to denote a plain saturable reactor). Steady-state and dynamic performance are examined. Here, as well as in subsequent chapters, occasional use is made of a square-wave supply voltage. Such a voltage shape greatly simplifies the graphical solution of transient problems, and is a very useful tool for didactic purposes.

Chapter 4 is entitled the "Self-Excited Transductor" (designated in the U. S. by saturable reactor with external feedback). The core material is assumed to have a flux-current loop of zero loop width, consisting of the familiar three straight lines, with saturation branches being horizontal. The loop width of the flux-current loop is, however, an important parameter affecting the saturable reactor with external feedback. While the assumption of zero loop width facilitates the analytical treatment, the assumption also introduces discrepancies with the observations made on actual amplifiers, since core materials with zero loop width are nonexistent. The next chapter is titled "Transductors with Auto-Excitation" (called self-saturated amplifier in the U. S.). The assumption regarding the flux-current loop is the same as in Chapter 4, and the treatment follows previously established methods. The effects of ac and dc inductive loads, and of dc capacitive loads, are treated in Chapter 6.

Chapters 7 and 8 deal with the dynamics of magnetic amplifiers. Time lags in the amplifier, as well as in inductive and capacitive loads, are discussed. The treatment is in the form of operational calculus, augmented by presentations in the gain-phase angle-frequency domain. Oscillograms and other measured data support the text convincingly. The following chapter gives a good account of amplifiers with half-cycle response. Chapter 10, "Balanced Magnetic Amplifier Circuits," deals effectively with various forms of push-pull circuitry. Chapter 11 is called "Low Level Amplification and Multi-Stage Amplifiers." A good account is rendered of various forms of drift, and the even-harmonic detector, both single-ended and push-pull. Very little, however, is said about multi-stage amplifiers although the chapter title carries this topic in its heading. A brief discussion of magnetic modulators is presented in Chapter 12.

"Construction and Design of Magnetic Amplifiers" is the title of Chapter 13, a chapter which is likely to become the most popular of the book. It contains a vast amount of practical information and also several design procedures which were so sorely missed in the literature. Concluding the book is a good selection of numerous applications of magnetic amplifiers.

In summary, this very interesting book covers a vast area of the magnetic amplifier art with the emphasis divided about evenly between theory and practice. The book is very well written, and many illustrations support the text. The terminology is that of Great Britain, however, which may lead to the occasional confusion of the U. S. reader. The very high degree of competence of the author makes itself felt on nearly every page.

This book will make many friends for Dr. Frost-Smith among practicing engineers and students alike. Congratulations are offered to the author for accomplishing such fine work.

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Progress in Metal Physics, Vol. 7, 1st Ed., edited by Bruce Chalmers

Published (1958) by Pergamon Press, Inc., 122 E. 55 St., N. Y. 22, N. Y. 395 pages+12 index pages+viii pages. Illus. 6×9¼. $16.00.

The "Progress in Metal Physics" series presents authoritative reviews of specialized subjects in the fields of physical metallurgy and metal physics. These reviews strive to summarize and appraise the existing state of knowledge in diverse areas. It is the hope of the editors that this series of timely reviews will help research workers keep abreast of developments in their own and closely related fields.

The present volume has the same high quality and pleasant balance as its predecessors. Included in this volume are the following five articles: 1) "Equilibrium, Diffusion, and Imperfections in Semiconductors," by J. N. Hobstetter (64 pages), is written on an introductory level, and contains a good deal of background material. It is designed to familiarize specialists in metal physics with the theoretical and experimental advantages of studying such phenomena as equilibrium, diffusion of atoms, and the generation and motion of dislocations and other imperfections in semiconductors. 2) "The Physical Metallurgy of Titanium Alloys," by R. I. Jaffee (100 pages), is a highly detailed account of titanium alloys, with emphasis on their crystallographic, metallurgical, thermal, and mechanical properties. A wealth of experimental data is presented, as well as a critical analysis of this data. The general impression is that the alloying of titanium is still largely an empirical science. 3) "Thermodynamics and Kinetics of Martensitic Transformations," by Larry Kaufman and Morris Cohen (81 pages), is a comprehensive and highly readable survey of the physical chemistry of martensitic (displacive or shear-like) reactions. There has been much noteworthy progress in the understanding of such reactions during the past decade, and this is capably summarized here. 4) "The Stored Energy of Cold Work," by A. L. Titchener and M. B. Bever (91 pages), is a well-organized and interestingly written account of the process of deformation by cold working, the nature of the cold-worked state, and the mechanisms of the restoration processes that occur in cold-worked metals. In addition to a well-documented survey of pertinent experimental investigations, there is a thoughtful section devoted to overall conclusions, a feature lacking in a few of the other articles in this volume. 5) "The Properties of Metals at Low Temperatures," by H. M. Rosenberg (55 pages), is a compact account of the electrical and thermal conductivity, the specific heat, and divers mechanical properties of metals and alloys at low temperatures, including the superconducting phase. A clear and well-balanced picture of the subject emerges from this paper.

This volume forms a welcome addition to the review literature. Each of the articles is well documented, and the value of the volume as a whole is enhanced by author and subject indices. It is expected that each of the articles will prove useful to a wide circle of readers.

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A Facsimile Edition of George Green's Essay on Electricity and Magnetism, by Stig Ekelöf

Published (1958) by Wezata-Melins Aktiebolag, Göteborg, Sweden. 72 pages+vii pages. 8×10½. Half Cloth Binding. The book will be sent postage free to any country on remittance of U. S. $5.00 or the equivalent in Swedish Kronor to Institute for Theoretical Electricity, Chalmers Institute of Technology, Göteborg, Sweden.

This most remarkable book is an original contribution to mathematics and to the theories of electricity and magnetism made 131 years ago by George Green, a 34 year old self-taught miller's son from Notting-

n. The exposition is a model of clarity d directness. Because of this and the fact at all modern books on advanced calculus d electrostatics still use the terms introced by George Green, the essay is very dable. It should certainly be most stimuing and inspirational to students struggling th Green's theorem, Green's functions, ., in courses on advanced calculus and rtial differential equations. Every college rary should have a copy.

On Page 1 Green creates a name "potential function" to facilitate thought and communication of ideas. The symbol for it, V, follows. On Page 3 he obtains the properties of potential functions in the interior of a charged surface and at infinity and establishes the continuity of potential functions across the surface. On Page 10 he enunciates and proves a theorem which we now know as Green's theorem. Generalizations of this theorem follow. Then come the expressions for the potential functions in the interior (or the exterior) of a closed surface in terms of their values or the values of their normal derivatives on the surface. It is here that Green introduces functions now known as Green's functions. The remainder of the essay is divided about equally between the applications of the general results to electrostatics and magnetostatics.

Congratulations to Professor Ekelöf on recalling from oblivion this mathematical masterpiece.

S. A. SCHELKUNOFF
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Murray Hill, N. J.

Abstracts of IRE Transactions

The following issues of TRANSACTIONS have recently been published, and are now available from the Institute of Radio Engineers, Inc., 1 East 79th Street, New York 21, N. Y. at the following prices. The contents of each issue and, where available, abstracts of technical papers are given below.

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* Libraries and colleges may purchase copies at IRE Member rates.

Component Parts

VOL. CP-6, NO. 1, MARCH, 1959

Information for Authors (p. 1)

Who's Who in PGCP—Louis Kahn, Member Administrative Committee July, 1958 to uly, 1961 (p. 2)

An Introduction to Inorganic Dielectrics—-K. H. McPhee (p. 3)

The characteristic behavior of inorganic ielectrics under thermal, electrical, and meanical stress is explained in terms of the tomic and molecular structure of matter. Ionconductors and conductors are treated as ifferent areas of a continuous materials spectum.

The nature and properties of constituent aw materials in representative ceramic bodies re discussed. The chemistry of their combinaon is analyzed and Gibbs phase rule is applied.

The phenomenon of plasticity in clay-water ystems and its application to forming and haping are examined. The manufacture of odies containing varying amounts of plastic ngredients is described, and the influence of orming techniques on resultant properties of hese bodies is shown.

A few of the more common dielectric materials are listed, and a number of good design practices are given.

Components for Submarine Telephone Cable Repeaters—M. C. Wooley (p. 34)

The first transatlantic, Alaskan, and Hawaiian Submarine Telephone Cables are provided with repeaters spaced about 37.5 miles apart. Each repeater consists of a 3-stage electron tube amplifier and contains approximately 60 components. Because of their inaccessibility for repair or replacement, it is desired that these systems operate for the order of 20 years without failure of any component. This requires a degree of reliability for both active and passive components and orders of magnitude higher than are achieved in more conventional systems.

Electron tubes and high-voltage capacitors subject to "wear out" have been the subject of intensive development and life testing for more than 15 years. These studies indicate that at the low cathode temperature and low cathode current density used in the electron tubes, satisfactory thermionic performance can be expected for more than 20 years. Likewise, tests on the high-voltage capacitors indicate that, in spite of the use of a high dielectric stress, the probability of a wear-out failure in 20 years is low.

These estimates, however, do not include the probability of catastrophic or sudden failure of the components. Since practicable test programs cannot measure the extremely low catastrophic failure rate expected of these components, it must be attained through the use of 1) reliable types, 2) close control of raw materials, 3) simple designs which are easy to make and inspect, 4) careful manufacture, and 5) thorough inspection.

This procedure is restrictive and involves close attention to all details in both design and manufacture. Consequently, unusually detailed specifications were required for raw materials, processes, and components. Complete records of all operations and inspections were kept to insure against omissions or errors. Specially selected operators were trained and required to demonstrate ability to produce satisfactorily before placed on production work. Manufacture was carried out under exceptionally clean conditions. The product was inspected at each stage of manufacture so that hidden defects would not be missed. The resulting slow and painstaking manufacture disclosed many defects which would have been overlooked in normal production.

Although no numerical value can be attached to the degree of reliability attained, experience in production and service to date indicate that it is unusually high. Over 270 million component hours of service without a failure have been accumulated to date, which indicates, with 90 per cent certainty, a failure rate of less than 1 in 10,000 per year.

A New Memory Device—The Twister—D. A. Ellerbruch (p. 42)

Although the "Twister" memory device is still in the experimental stage at the Bell Laboratories, great expectations for its use in the future may be considered. Very favorable performance results have been obtained in the past, and if the results are as favorable in the future, it may eventually replace many of the magnetic core and drum types of memory systems. Physical size of the Twister memory device may be small due to the diameter of the magnetic wires used and the high-storage density of an array.

Contributors (p. 45)

Education

VOL. E-2, NO. 2, APRIL, 1959

Special Issue—Sagamore Conference on Electrical Engineering Education, May 30–June 1, 1958

Editorial—Wilbur R. Lepage (p. 32)

Advanced Education—Past, Present, and Future—F. Hamburger, Jr. (p. 33)

A brief historical review of education beyond the baccalaureate with particular emphasis on graduate study in electrical engineering is followed by an examination of present trends. Consideration is given to such topics as admission requirements, programs of study, graduation requirements, and residence requirements as they affect students. Staff factors such as qualifications, load, compensation, research, and advancement are considered. The problems that must be examined to assure a healthy future are listed to stimulate continuing discussion.

Industry's Contributions and Needs in Graduate Education—David F. Kline (p. 40)

The General Electric Company provides, within its Advanced Technical Programs for Engineers and Scientists, a logical sequence of courses for the development of these men. Within this framework of courses is the Honors Program for Graduate Study, which enables the motivated engineer or scientist to complete requirements for the Master's degree. The opportunity is also present to continue further his educational development through the Advanced Engineering Program, the Creative Engineering Program, or a Tuition Refund Program.

The Challenges in the Development of Graduate Programs—Ernst Weber (p. 41)

In order to protect the integrity of graduate degrees, the basic objectives of graduate study must be examined and interpreted in the widest sense, taking into consideration changing social conditions. This paper traces the development of graduate engineering education from World War I, with its original attachment to the established pattern of graduate study in university science departments. It considers the place of research in graduate study and the problems arising from the need for research sponsorship today. Also, attention is focused upon the classification problems arising from the large number of part-time graduate students enrolled in engineering schools today.

Current Developments in Patterns of Graduate Study—Newman A. Hall (p. 45)

During recent years considerable attention has been given to an analysis of the changing patterns of graduate study in engineering. Reviews by the American Society for Engineering Education, the University of Chicago under a Carnegie Grant, and the Ford Foundation have been directed to the problem. A primary observation has indicated a trend towards greater diversity in patterns and a closer correlation with current requirements of research and development in industry and government. These patterns, inlcuding evening and various forms of off-campus training, are described and their effect on the nature of the graduate program is examined. The effect of direct and indirect industry support is analyzed, and the changing role of the faculty in cases where close coordination with industry exists is examined. Current trends are evidently enriching and strengthening the value of the graduate program, particularly through immediate contact by both student and faculty with research and development applications. There exists, however, a consequent overemphasis on immediate needs, and an ambiguity of long-range academic objectives. The critical financial needs of students, faculty, and engineering educational institutions are emphasized by the demands of new patterns and current high standards of academic endeavor.

Off-Campus Resident Graduate Programs at Company Centers

The Syracuse-IBM Program—R. A. Galbraith (p. 52) and J. R. Lakin (p. 53)

The R.P.I.-United Aircraft Program—Warren C. Stoker (p. 55) and G. C. Barnes (p. 58)

The NYU-Bell Labs Program—S. S. Shamis (p. 60) and S. B. Ingram (p. 62)

Question and Answer Period Following Panel Discussion (p. 64)

Contributors (p. 66)

Electron Devices

Vol. ED-6, No. 2, April, 1959

Frequency Characteristics of a Semiconductor Rectifier at Voltages Greater than kT/q—L. Depian, W. E. Newell, and A. G. Milnes (p. 125)

In this paper, the frequency characteristics of a half-wave p-n junction rectifier with a resistance load are analyzed for applied voltages greater than kT/q. Beginning with the derivation of an implicit integral equation which describes the large-signal operation of this circuit, the effect of frequency on the rectification efficiency is then obtained from an iterative numerical solution of this equation using an IBM 650 computer. Contrary to the small-signal theory developed by Kalashnikov and Penin, it is found that at higher applied voltages the half-power frequency is very dependent on voltage as well as load resistance, carrier lifetime and reverse saturation current. The relationships between the half-power frequency and these parameters are shown graphically, and the results are compared to the small-signal theory for small applied voltages.

A Lumped Model Analysis of Noise in Semiconductor Devices—R. N. Beatie (p. 133)

A clear picture of the noise properties of semiconductor devices may be gained through a study of lumped models. When a semiconductor device is represented by a lumped model it is found that all the noise may be accounted for by associating a noise-current generator with each of the conductances appearing in the lumped model. The expressions describing these noise-current generators are easily found, and the determination of the device noise properties involves only lumped model analysis.

Such analysis applied to a diode model and a transistor model yields results which are in agreement with the results of other authors, and with experimental measurements cited by them. The mechanisms considered in this paper do not, however, account for the so-called 1/f noise.

A Physical Theory of Junction Transistors in the Collector-Voltage-Saturation Region—C. Huang (p. 141)

A physical theory has been formulated for the operation of junction transistors in the "collector-voltage-saturation" region or "on" region. Transistor characteristics in this region are important for switching applications, Class A or Class B amplifiers, as well as other large signal applications. The formulation is based on the physical consideration that in the "collector-voltage-saturation" region the collector-base junction is forwardly biased, and that the injection level is high.

Two-dimensional distributions of carrier densities, current densities, and electric field are obtained for separate portions of the base region. Using these distributions, theoretical expressions are derived for the characteristics of p-n-p and n-p-n transistors including saturation voltage, base input voltage, and dc current amplification factor. Good agreement between theoretical and experimental results indicates that the approximations used in the theory are valid. Numerical calculations have been carried out for the saturation voltage, base input voltage, and dc current amplification factor for different geometrics and material properties. The calculation shows the use of the theory for quantitative designs of transistor characteristics.

Surface and Geometry Effects on Large Signal Base Input Voltage and Input Resistance of Junction Transistors—C. Huang, C. M. Chang, and M. Weissenstern (p. 154)

A design theory for large signal base input voltage and input resistance of junction transistors is presented with emphasis on the effect of surface recombination and transistor geometry.

Two-dimensional distributions of minority carrier density and electric field are obtained for the separate portions of the base region. These distributions are then expressed in terms of emitter current and are used to derive expressions for the large signal base input voltage and resistance. The dependence of carrier distribution on surface recombination velocity and transistor geometry is illustrated by curves.

The theory is corroborated by a series of experiments carried out with p-n-p power transistors. The parameters varied are surface recombination velocity (by baking), emitter diameter, base ring diameter, dice thickness and base region resistivity. The measured base input voltage and resistance are plotted and compared with calculated values based on the theory presented. Good agreement is found between calculated and measured values. The results deviate in several interesting respects from the values predicted by the small signal or low injection level theory. Based on this theory, design considerations for the large signal input voltage and input resistance are discussed.

On the Theory of DC Amplification Factors of Junction Transistors—S. Wang and T. T. Wu (p. 162)

According to Webster's phenomenological theory, the base current consists of three terms arising from 1) surface recombination, 2) bulk recombination, and 3) non-unity emitter efficiency. In this paper, the diffusion equation inside the base region of an alloyed transistor is solved, and an analytic expression for the dc amplification factor is presented in terms of arbitrary bulk lifetime and surface-recombination velocity and the geometry of the transistor. The surface-recombination term depends on the distribution of the injected carriers along the emitter-base boundary, and hence it increases as the emitter current increases on account of the base-resistance bias effect which tends to concentrate the minority carriers near the periphery of the emitter. The falloff in beta at high-emitter current is attributed mainly to an increase in the surface-recombination term, contrary to Webster's theory. A comparison with Webster's theory is made on units having the same bulk property but different surface treatments. Experimental results give strong support to the present theory.

An Alloy-Diffuse Silicon High Current Transistor With Fast-Switching Possibilities—D. Navon and P. Debeurs (p. 169)

A method is described for the fabrication of a high-power silicon transistor capable of operating at case temperatures exceeding 100°C. Large-area transistors can be produced having uniform base widths of a few ten-thousandths of an inch. The base is established by the diffusion of impurities from a double-doped alloyed contact on the surface of the silicon. This device gives a common emitter current gain of greater than 30 at 10 amperes collector current and can dissipate 100 watts if the case temperature is held below 55°C. In addition it has constant common emitter current gain out to 200 kc. Hence this technique produces a power device combining both good current gain and frequency characteristics.

High-Level Transistor Operation and Transport Capacitance—K. E. Mortenson (p. 174)

A two-dimensional analysis of high-level transistor operation is presented which includes the effects of an extended base region

nternal emitter biasing, γ-falloff, unequal ollector and emitter dimensions, and surface ecombination.

The transistor model considered is directly ppropriate to the strip-type geometry, but lso yields results which are approximately alid for the ring- and dot-type structures under ertain conditions. Transforming the geometry ermits a solution to be obtained for the charge-ensity distribution in the base as well as the urrent density distribution at the emitter nd collector junctions. From these relations, oth the collector and emitter transport (dif-usion) capacitances are also determined.

Two complete numerical evaluations of the heoretical results are given, first for a sym-metrical unit with equal emitter and collector limensions, and second for an unsymmetrical nit with the collector dimension 24 per cent greater than that of the emitter. It is indicated hat an appreciable fraction of the total base harge can exist external to the emitter and col-ector, particularly for very high-level opera-ion, causing large increases (1.5 to 3 times the one-dimensional values) in both the emitter and collector transport capacitances, particu-larly for units having grossly extended base regions and low-surface recombination veloci-ties. Further shown is the effect of increasing the collector dimension over that of the emit-ter; the capacitances are appreciably lowered and the transport efficiency (and thus the cur-rent gains) is increased.

Finally, some collector transport capaci-tance measurements are presented covering the entire operating range which tend to substan-tiate the theoretical results.

Impedance and Dispersion Characteristics of the Flattened Helix—C. C. Johnson (p. 189)

Curves are presented which give the dis-persion and impedance characteristics of a flattened helix in the presence of a dielectric material and a metal shield. The impedance curves are very similar to the corresponding curves for a round helix whose circumference is equal to the perimeter of the flattened helix. The flattened helix has dispersion character-istics similar to a round helix whose diameter equals the flattened helix thickness.

An Investigation and Application of the Contrawound Helix—J. E. Nevins, Jr. (p. 195)

An investigation of the contrawound helix and the determination of its characteristics has been completed. By means of a hollow-beam traveling-wave tube and perturbation methods, the fundamental and minus-one space harmonics impedances have been meas-ured and a number of space harmonics of the symmetric and antisymmetric modes identified.

The fundamental impedance was measured to be equal or greater than the sheath-helix impedance depending, however, upon the thickness and width of the helix tape. The minus-one space harmonic impedance was measured to be larger than the fundamental impedance for $ka > 0.65$.

The contrawound helix has been employed as a high-power X-band amplifier (8.5–9.5 kmc). The characteristics of the tube described are 25-db gain, power out > 1 kw, efficiency 7–10 per cent.

Bibliography on Electroluminescence and Related Topics—H. F. Ivey (p. 203)

Propagation of Space-Cherge Waves in Diodes and Drift Spaces—H. G. Kosmahl (p. 225)

It has generally been found that propaga-tion of space-charge waves may be described 1) in space-charge-limited gaps by Gauss' hypergeometric functions; 2) in gaps with no space charge but with an accelerating homo-geneous field by Bessel functions with real argu-ment; and 3) in spaces free of dc fields by sim-ple trigonometric functions. The equations de-rived become simpler through the selection of the dc velocity μ, rather than the time t, as the independent variable.

Disturbances in a Multi-Velocity Plasma—J. R. Pierce and J. A. Morrison (p. 231)

The single-velocity treatment of ac dis-turbances in electron flow is often accurate enough even when the flow actually has an in-finitely broad but peaked velocity distribution, such as a Maxwellian or a bell-shaped distribu-tion. In seeking a better approximation, one is tempted to expand in terms of the moments of the velocity distribution and to disregard terms beyond that involving the second moment. This leads to a dispersion equation describing waves which have no physical existence. A linearized analysis by transform methods pre-dicts a field which oscillates in an exponentially damped manner. This is not the oscillation of a normal mode, however, for various velocity classes of the charge distribution have ac densi-ties which grow with time. This indicates that linear expression will hold over a finite interval only.

A simple example which compares a multi-stream analysis with an analysis based on the charge density in phase space (the distribution function) indicates the same sort of failure of both of the linearized theories at large times. Thus, it appears that the failure is character-istic of the problem rather than of the method of solution. The method of solution is a matter of choice.

A Self-Excited Drift-Tube Klystron Frequency Multiplier for Use in Generating Millimeter Waves—W. H. Cortetet, Jr. (p. 236)

Theoretical and experimental considera-tions are presented in this paper for a self-excited frequency multiplier in which the funda-mental oscillator is an integral cavity two-gap klystron and a harmonic resonator is placed at an appropriate position in the drift tube be-tween the two gaps. This is a new device and it is called a drift-tube klystron frequency multiplier abbreviated as DTKFM.

A general design procedure is given, based on both theoretical equations and experimental characteristics. Operation of the self-excited DTKFM with fundamental oscillations at 4 and 1 cm and harmonics at 1 cm and 5 mm re-spectively, is presented. The device is capable of generating larger CW output power at milli-meter wavelengths than many existing devices.

Experimental Notes and Techniques

A High-Frequency Alpha Cutoff Jig—L. M. Terman (p. 242)

Magnetron Cathode Arm Radiation and Luminescence—R. A. White and A. Bamford (p. 242)

Program of 1958 Electron Devices Meeting, October 30–31, Washington, D. C.—(p. 243)

Contributors (p. 254)

Engineering Management

Vol. EM-6, No. 1, March, 1959

An Oscilloscopic View of the Electrical Industry by Investment Capital—C. M. Bower (p. 1)

Research and Development Cost Estimation—V. L. Lambert and H. F. Sackett (p. 8)

Four companies engaged in research and development were interviewed relative to their method of cost prediction. Company A, engaged in military equipment development, uses a complex operating organization to make estimates. Company B, engaged in commercial development, uses a summary unit cost, *i.e.*, number or predicted man years multiplied by a given number of dollars. Company C, commercial research and development, estimates on the basis of individual projects but holds department managers accountable only for total department costs. Company D, government research and development, uses the future operating structure as does Company A, but seems to use a less complex structure. A further investigation into the use of summary unit costs is recommended.

Industry-University Cooperation in the Field of Research—R. I. Cole (p. 12)

Recruiting the Technically Creative—A Dual Responsibility—J. Kurshan (p. 14)

Effective recruiting requires teamwork be-tween the personnel staff and the research and development organization; neither should shirk its responsibilities. Effective organization for the task of recruiting creative engineers and scientists will also improve the recruiting of engineers in general.

Creative individuals are especially sensitive to the nonmaterialistic aspects of their working environment. These include the nature of the work, reputation of the organization, opportu-nities for growth, quality of supervision, and living conditions.

With reference to the applicant, recruiting may be divided into six basic elements: attract-ing, screening, visiting, interviewing, decision-making, and follow-up. All involve participa-tion by both line and staff parts of the organi-zation, but the responsibilities of each group are distinct.

The personnel staff has the basic responsi-bilities of providing professional employment guidance and of handling administrative de-tails. These duties include personnel research, employment planning, organizing the recruit-ing effort, training recruiters, screening appli-cants for further consideration, arranging lab-oratory or plant visits, interviewing from a nontechnical viewpoint, and coordinating the action on the decision, the offer, and the sub-sequent follow-up.

Technical management must set its own manpower requirements, both quantitatively and qualitatively, and make the final decision whether to hire a given individual. Nonsuper-visory technical personnel can contribute effec-tively in attracting, recruiting, and interviewing applicants. Criteria are discussed for selecting people to do the recruiting tasks.

A Forward Look at Management Develop-ment—R. K. Greenleaf (p. 19)

Merit Rating and Productivity in an Industrial Research Laboratory: A Case Study—A. G. Grasberg (p. 31)

A merit rating plan based only on one cri-terion, over-all performance, was tested in one section of approximately sixty engineer-scientists in a large industrial research lab-oratory. The procedure used is discussed along with some general results. In addition, a meas-ure of individual productivity was developed based on the average number of technical re-ports, publications, and patent disclosures written per year. A fairly good correlation was found between the merit ratings and the meas-ure of productivity.

"Proselyting"—Good Business?—R. G. Swander (p. 37)

For Your Bookshelf (p. 40)

Industrial Electronics

Vol. IE-9, April, 1959

Design of a High-Performance Instrument Servo for General Purpose Computation—K. V. Bailey and M. A. Ziniuk (p. 1)

A computing servo capable of accurate rate and position operation with extended fre-quency response relative to conventional com-puting servos is described. The usual tachom-eter generator with its penalizing inertia is avoided in this design. Rate feedback is pro-vided instead by a precision capacitor which couples the follow-up potentiometer to the input summing junction. Design objectives, com-promises, and performance data are reviewed.

Electronics in Automatic Mail Cancelling and Facing—P. W. Barnhart (p. 14)

An automatic mail cancelling and facing machine has been developed which processes 500 letters per minute in a single pass. Letters are introduced into the complex, five-module machine system in random postage stamp orientations, high or low, leading or trailing. Stamp locations are individually detected by flying spot scanners. These scanners generate command signals for the selective actuation of the appropriate one of twelve cancelling heads and for the subsequent direction of the letter to one of four terminal letter collection stackers in which all letters are uniformly faced, that is, with stamps, and therefore addresses, oriented in the same manner.

An Automatically Controlled Vertical Turret Lathe—A. O. Fitzner (p. 19)

This paper describes a punched-tape control system for a vertical turret lathe having a rail head and a side head. The system exercises complete control over turret indexing, tool feeds, table speed, tool dwell, etc. Coordination of the operations of the two heads is obtained by proper wording of the program. Calibrated adjusting potentiometers (automatically selected by the control) have been provided to allow the operator to compensate for tool deflections, and the like, on critical workpiece dimensions. Novel features such as single-cycle operation, single-head operation, and operation repeat have been incorporated in the control to facilitate the setup procedure.

Programming is simple and direct, with no equipment required other than a standard 8 channel Flexowriter.

Minimizing Production Costs Through Modular Automatic Test Equipment—J. Tampico and H. B. Rose (p. 29)

The dominant consideration influencing the trend toward automatic test and checkout techniques for production-line test stations is cost reduction. Testing costs includes the costs of test equipment and spares, of operating and maintaining personnel, of floor space, and of down time. As test cost per unit produced is the basis for comparison, the test rate achieved per station is a major factor. An analysis of test station requirements for a mass-produced missile is used as an example. This analysis shows major reductions in test cost per unit as a result of automation for subassemblies which have fairly complex test requirements; whereas for simple subassemblies, there are no cost improvements and manual testing is quite satisfactory.

The necessity for maintaining high test rates with fewer, less skilled operators and with the corresponding reduction in test stations imposes high reliability requirements on automated equipment in order to preserve this economic advantage. Therefore, such features as self-checking, fail-safe design, and printed-out test results are essential.

The construction of automatic test sets from functional universal modules reduces first cost of equipment, permits rapid and economic servicing, and reduces obsolescence of equipment. Another advantage of the modular approach to production-line test set design is that test sets using only a low order of automation may utilize modules identical to those of the fully automated equipment. This extends the "break-even" point in the choice between automated and manual equipment towards increased application of the more sophisticated techniques.

Data or Information—E. A. Keller (p. 35)

Information Theory

Vol. IT-5, No. 1, March, 1959

Frontispiece—Joseph L. Dobb (p. 2)

Editorial—Joseph L. Dobb (p. 3)

Correlation and Delay Line Attenuation—M. J. Jacobson (p. 4)

The effect of delay line attenuation on the output of a correlator is studied for the case where the attenuation in db to within a frequency independent loss varies linearly with delay and as the square root of frequency. It is shown how attenuation affects the output signal-noise ratio of the correlator, increasing it for some signal spectrum shapes and decreasing it for others. Upper bounds on the increase and decrease are computed and a sufficient condition on the input signal spectrum is established which, when satisfied, assures a degradation in signal-noise ratio. Also examined is the effect of a frequency independent gain inserted to compensate for the delay line attenuation. It is shown how this gain may be chosen in order to give uniform system output noise over all values of delay.

On the First Probability of Detection by a Radar Receiver System—W. M. Stone, R. L. Brock, and K. J. Hammerle (p. 9)

Expressions for the detection probabilities associated with the output of filter-square law detector-filter radar receivers are presented for practical filter systems and with a slowly varying Rayleigh distributed signal amplitude.

Full Decodable Code-Word Sets—M. P. Schutzenberger and R. S. Markus (p. 12)

This paper considers further how the decodability condition imposes restrictions on a set of code words. A generating function is defined that describes the composition of the code words. The relation between the generating function and a "full" set of code words is found. This relation shows that the sum of arbitrary probabilities associated with the words of a full set must be one. A full set of code words is one to which no code word can be added and still keep the set decodable. It is also shown that a full set is "completable." For a completable set of code words any string of symbols can be made into a sentence by adding a suitable prefix and a suffix.

On a Property of Wiener Filters—Moshe Zakai (p. 15)

Let $Y(\omega, \alpha)$ be the Wiener filter designed to yield an output which is the least-square approximation to $s(t+\alpha)$ where $s(t)$ is the desired signal input. Let $Y_L(\omega)$ be the Wiener filter designed to yield an output which is the least-square approximation to some linear operation L on the desired signal input. The following simple relationship has been shown to hold between $Y(\omega, \alpha)$ and $Y_L(\omega)$. If $s(t)$ is the desired signal input and $L_\alpha[s(t+\alpha)]$ is the desired output, where L is some linear operation with respect to α, then $Y_L(\omega) = L_\alpha[Y(\omega, \alpha^\alpha)]$.

Machine Recognition of Hand-Sent Morse Code—B. Gold (p. 17)

A transistorized special purpose digital computer called MAUDE (Morse AUtomatic DEcoder) has been designed, built and analyzed. This computer decodes a hand-sent Morse message, which is printed on a teletypewriter.

MAUDE'S decisions take place at a number of different levels, and its "knowledge" is not only that of relative durations of dots and dashes, but also of the Morse code and even of certain elementary properties of language.

MAUDE has successfully decoded between 90 per cent and 95 per cent of 184 operators. A successful decoding is one which results in a text which can be easily read by a man who knows the language.

It is felt that MAUDE can be a practical piece of equipment for a site with heavy traffic. Its performance will be inferior to that of a man until more sophisticated language rules, using at least a word vocabulary, are included.

The Morse Distribution—M. Freimer, B. Gold, and A. L. Tritter (p. 25)

A problem which arose during research involved in designing a machine to translate hand-keyed Morse code into printed text may be stated as follows: Let $X = \{x_i: i = 1, 2, \cdots, n\}$ be a sequence of independent random variables all of which have the same distribution. Assume that the probability that $x_i = x_j$, $i \neq j$, is zero. Let k be a positive integer $\leq n$, and consider all subsequences $x_i, x_{i+1}, \cdots, x_{i+k-1}$ of X consisting of k consecutive variables. Let us distinguish, with a check ($\surd$), the largest member of each such subsequence. We have studied, and partially tabulated, $p_n{}^k(r)$, the probability that exactly r members of the sequence X are not checked. This paper contains most of the pertinent results.

Correspondence (p. 32)

Contributors (p. 35)

Roster of PGIT Members (p. 37)

Instrumentation

Vol. I-8, No. 1, March, 1959

Abstracts (p. 2)

A High-Speed Low-Level Scanner—K. Enslein (p. 3)

The scanner to be described in this paper has as its general specifications the following requirements: scan 500 pairs of strain-gauge inputs at a repetition rate of 50 pairs per second under control of a train of control pulses. A minimum dwell time of 5 msec is needed. The output of this scanner is to be connected to a high-speed digital voltmeter. This digitizer in turn feeds an IBM 727 tape unit. The data from the tapes are then to be processed by an IBM 704. Life, therefore, should be compatible with that of the associated equipment.

This scanner should then combine two features usually only available independently: its life should be such that at least 20,000,000 operations can be expected without readjustment and the scanning rate must be at least 50 points per second. In addition, the contact noise level must be extremely low due to the small amplitude of the strain-gauge signals. (There is, in this respect, one advantage: the strain-gauges are of rather low impedance.) The low-noise requirement is usually satisfied by means of very high quality relays. These are, however, inherently rather slow. The high-speed requirement could be satisfied either by electronic circuitry, which would be either prohibitively expensive for this noise level requirement, or by rotary sampling switches. The latter, while quiet and fast enough, are extremely restricted in their life span.

Aperture Corrective Systems—J. Otterman (p. 8)

This paper is concerned with the averaging or smoothing effect common to a large variety of sensing devices, *i.e.*, devices that convert a signal in one form of energy into a signal in another form of energy. The distortion is known as an aperture effect since it appears in the instrumentation system that converts spot-by-spot light intensity in a picture into a continuous electric signal by aperture scanning. The correction for this effect can be achieved by incorporating a compensating electrical network in the instrumentation system.

The compensating circuits described in this paper represent a new approach to the problem of compensation. The transfer functions of the circuits suggested are inverse to those of the apertures, except for small departures introduced to insure stability or caused by losses in delay lines. The common property of all these circuits is that they incorporate a delay device in the feedback loop of an active element or a delay line mismatched at both ends. The impulse responses possess some repetitive character.

The compensating method offers special

dvantages when some preferred forms of aperture, such as the birectangular or exponential, an be used.

Application of Quasi-Peak Detector to the Measurement of Probability Density Function—K. Y. Ya'coub (p. 19)

An application of the quasi-peak detector, which is found in radio noise meters, is considered as a device for measuring probability density function. Two procedures are discussed: one for obtaining the probability density function at discrete values of the variable, the second for approximating the entire function by using Edgesworth series.

Relative Voltmeter for "VHF/UHF Signal Generator Attenuator Calibration"—B. O. Weinschel, G. U. Sorgor, and A. L. Hedrick (p. 22)

This paper describes a system for the calibration of a signal generator. The system includes a linear mixer, a standard 30-mc source, a piston attenuator and a detecting system. Changes in the signal generator output are matched against changes in the piston attenuator, which is used as a standard. It is capable of measuring insertion loss, or differences in signal level over a range of 62 db with an accuracy of 0.02 db per 10 db.

IF Stabilization by Regenerative Frequency Conversion—D. M. Makow (p. 32)

A feedback system is considered using three mixers M1, M2 and M3. An external input frequency f_0 and an internally generated frequency f_b produce in M1 the difference $f_0-f_b=f_a$, which is applied to M2 and M3. Also f_b is applied to M2, which then generates $f_a=f_0$. This frequency is in turn fed to M3, where f_b is obtained as a difference of f_a and f_a. The frequency f_b closes the loop providing the originally assumed inputs to M1 and M2. The output frequency of M2 is identical with f_0, while f_b is determined by the zero-phase shift condition in the oscillatory loop formed by the branches connecting M2 and M3.

In a converter where f_a is chosen much smaller than f_b, f_a can be thought to be the IF and f_b the LO frequency. When certain design requirements are fulfilled, variations in the input frequency f_0 will not greatly affect f_a or f_b. Also, improvement in the stability of f_b due to drifts in d and b can be shown to be possible, where d and b are the phase angles introduced to f_a and f_b.

Correspondence (p. 36)

Vehicular Communications

Vol. VC-12, April, 1959

Ninth National Conference of the PGVC, December 4–5, 1958

Investigation of Antennas for Two-Way Mobile Communications in the VHF and UHF Regions—E. F. Harris (p. 2)

Due to the nature of two-way mobile communications the normal requirement is for base station antennas, as well as the vehicular antennas, to have radiation characteristics which are omnidirectional in azimuth. It is therefore necessary first to investigate the spatial distribution of energy and then to investigate means for confining the radiation in the elevation plane so far as possible to that region of space which represents the path for communication. Scale model techniques have been employed using 1/20 scale automobile mounted on a turntable ground plane to yield useful radiation pattern information for the mobile unit. Data are given for the quarter-wave roof mounted whip antenna and a bumper mounted coaxial antenna, plus a colinear array. For the base station, as well as the mobile unit, it is pointed out that the majority of communication takes place within one degree of the horizon. Pattern shaping techniques and tower and pole mounting effects are shown for various situations of side tower mounted arrays, both to allow for the tower consideration in those systems where side of tower mounting is a necessity and to enable the designer to take advantage of tower shaping situations where they can be used to increase gain in the desired directions. A newly developed three wavelength aperture colinear array for the vehicular unit for the 450 mc range is described. This unit is approximately 6 feet long over all and tests indicate a great improvement in systems performance over standard quarter-wave whip or dipole type antennas.

Antenna-to-Mast Coupling in Communication—M. W. Scheldorf (p. 5)

The use of vertically polarized antenna systems in the communication industry has been standard for quite a period of time. This standard results in a major part from the need for omnidirectional patterns with mobile stations and the fact that this solution is made in the simplest most direct manner by using a vertical conductor mounted over some metallic surface of the vehicle. In this application the vehicle surface becomes a very satisfactory horizontally disposed reflector, and the operating structure becomes fundamentally what is known as a ground plane antenna. That this choice of polarization places a handicap on the design of the station antenna is not a commonly well known fact. The problem in this connection arises from the inability to provide relatively large conducting ground plane surfaces at the top of tower structures used to mount these antennas at suitable heights for effective propagation. This paper is intended to discuss the problem in detail and to describe tests for measuring the effectiveness of solutions that are developed.

Identifying 450 MC Interference Using a Tunable Receiver and a Panadaptor—R. J. Klein (p. 13)

Many mobile systems operating in the 450–470 mc band are troubled by radio interference. Much of this interference is caused by intermodulation and spurious radiation from other systems operating in the same geographical area and frequency band. Due to the nature of intermodulation and spurious radiation interference, any intelligence originating from the interfering stations is obscured. This makes it impossible to identify them. If the stations causing the interference cannot be identified, it is difficult to take steps to eliminate the interference.

This paper describes how a 450–470 mc tunable receiver and Panadaptor can be used to identify interference. By scanning the band visually and aurally in 200 kc steps, the fundamental frequencies of the interfering stations can be found. Knowing these frequencies, the stations can be identified.

Transmission Test of a Trial System of Telephone Service for Aircraft—R. V. Crawford (p. 20)

This paper gives results of transmission tests on the air-to-ground telephone system which is presently in operation at 450 mc on a trial basis with land base stations located at Chicago and near Detroit. Received carrier level measurements, using a chart recorder, were made at both land stations prior to the start of commercial service on September 15, 1957. The effects of base station antenna height, aircraft elevation and distance from base station, nulling, capture in the overlap zone, and aircraft antenna patterns are discussed.

Shadows of the Future in Vehicular Communication—D. C. Pinkerton (p. 27)

This paper constitutes a discussion of certain changes in vehicular communication services and equipment that may be expected in the not too remote future. These changes are related, not only to technology, but also to the problems created by the slow but sure depletion of the available radio frequency spectrum space.

Attention is directed to the great potential that exists for better utilization of the spectrum through improvements in the space (or volume) and time dimensions. It is pointed out that the effective use of air time through automation of routine or repetitive type communications promises to give, in effect, a many-fold increase in the available spectrum.

A New Era in Communications Through Transistors—W. J. Weisz (p. 35)

Bias Considerations in Transistor Applications to Communications Circuitry—A. G. Manke (p. 47)

Transistorized Power Supplies for Higher Input Voltages—L. S. Pearlman (p. 54)

The Use of Miniature Tubes in Class C Circuits—A. Dzik (p. 58)

Receiving-type tubes designed primarily for small-signal class A applications are being used in an increasing number of class C circuits in mobile transmitters and other revenue bearing industrial equipment requiring a high degree of reliability. Tube performance in such circuits is often limited by the effects of class C operation on the individual elements of the tubes. This paper analyzes such effects in the RCA 7054, a miniature sharp-cutoff pentode designed for use as a low-level frequency multiplier in mobile service, and describes circuit-design techniques which can be used to improve equipment reliability.

Application of Vehicular Communications to Railroads—L. R. Thomas (p. 62)

Selective Signaling in the Bell System—Relay to Transistor—W. G. Chaney (p. 67)

Selective Signaling is used in Domestic Public Land Mobile Systems by many telephone companies to individually call vehicles equipped for mobile telephone service. Problems of reliability, speed, simplicity and number capacity, rule out many possible systems. A mechanical device used successfully for the past years is now proving both bulky and costly so that newer devices are under consideration.

A description of the present day system is given in this paper inasmuch as any new equipment will be expected to perform in a compatible manner.

A Transistorized Selectror Device for Bell System Mobile Telephone Service—J. R. Scantlin (p. 71)

A Digital Selective Signaling System for Mobile Radio—J. H. Green and J. Gordon (p. 74)

A system for remote operation of a particular receiver selected from any number of similar receivers, all using a very narrow bandwidth, is described. Two tones that are turned on or off according to an address-determining binary sequence are transmitted to a group of receivers, one of which will recognize the address, or call, and activate a control circuit. A small transistorized experimental model with low power consumption, was built to prove the system.

New Ruggedized Hand-Held Microphone for Mobile Radio Equipment—A Brouns, G. Salisbury, and R. Troxel (p. 86)

The increased use of mobile radio equipment has resulted in an emphasis on intelligibility, reliability and a decrease in cost and weight.

The use of the controlled magnetic cartridge in place of carbon has done a very effective job of increasing intelligibility.

The use of plastic in the case of a hand held microphone has resulted in a reduction in both cost and weight. Using some of the new high impact plastics, the case demonstrates physical characteristics that exceed those of metal on almost every point. This plus other modifications in the mechanical and electrical design of the unit gives a microphone that is more reliable at extremes in operational environmental conditions that are incurred in mobile use.

Abstracts and References

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NOTE: The Institute of Radio Engineers does not have available copies of the publications mentioned in these papers, nor does it have reprints of the articles abstracted. Correspondence regarding these articles and requests for their procurement should be addressed to the individual publications, not to the IRE.

Acoustics and Audio Frequencies..... 1176
Antennas and Transmission Lines..... 1176
Automatic Computers..... 1177
Circuits and Circuit Elements..... 1177
General Physics..... 1179
Geophysical and Extraterrestrial Phenomena..... 1179
Location and Aids to Navigation..... 1182
Materials and Subsidiary Techniques.. 1182
Mathematics..... 1184
Measurements and Test Gear..... 1184
Other Applications of Radio and Electronics..... 1185
Propagation of Waves..... 1185
Reception..... 1186
Stations and Communication Systems.. 1186
Subsidiary Apparatus..... 1186
Television and Phototelegraphy..... 1187
Tubes and Thermionics..... 1187
Miscellaneous..... 1188

The number in heavy type at the upper left of each Abstract is its Universal Decimal Classification number. The number in heavy type at the top right is the serial number of the Abstract. DC numbers marked with a dagger (†) must be regarded as provisional.

The Index to the Abstracts and References published in the PROC. IRE from February, 1958 through January, 1959 is published by the PROC. IRE, May, 1959, Part II. It is also published by *Electronic and Radio Engineer*, incorporating *Wireless Engineer*, and included in the March, 1959 issue of that journal. Included with the Index is a selected list of journals scanned for abstracting with publishers' addresses.

ACOUSTICS AND AUDIO FREQUENCIES

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Theoretical Investigation of an Ultrasonic Field—N. Segard and J. Cassette. (*Compt. rend. Acad. Sci., Paris*, vol. 247, pp. 809–812; September 15, 1958.) The changes of pressure in a liquid caused by the vibrations of a piston-like quartz resonator are evaluated.

534.414:534.84 1424
Investigations of Nonlinear Helmholtz Resonators—F. Barthel. (*Frequenz*, vol. 12, pp. 72–82; March, 1958.) The causes of nonlinearity of the absorption coefficient in resonators as a function of sound intensity are analyzed. Emphasizing these nonlinearities may be useful in improving room acoustics.

534.6:681.8 1425
The Use of the Acoustic Spectrograph and the Problem of the Score in Experimental Music—A. Moles and V. Ussachevsky. (*Ann. Télécommun.*, vol. 12, pp. 299–304; September, 1957.)

534.75 1426
Investigation of the Sensation of Loudness of Rhythmic Sounds—H. Niese. (*Hochfreq. und Elektroak.*, vol. 66, pp. 115–125; January, 1958.) Subjective tests on sinusoidal tones with sine-wave, rectangular-wave or pulse modulation show that loudness appears to increase at modulation frequencies below about 100 cps. Results are compared with calculations of this "inertia" effect in hearing, and conclusions are drawn for the design of objective loudness meters.

534.79 1427
Proposal for a Loudness Meter for an Acoustically True Indication of Sounds with Peaked Waveform in Acoustic Fields of Any Form—H. Niese. (*Hochfreq. und Elektroak.*, vol. 66, pp. 125–139; January, 1958.)

534.84 1428
On the Use of the Iteration Method in Room Acoustics—A. Moles. (*Ann. Télécommun.*, vol. 12, pp. 443–444; December, 1957.) A study of the progressive distortion of music or speech shows a separation of the relative constants of semantic and aesthetic information in each.

621.395.61:621.3.082 1429
Research on Probe Microphones—I. Barducci and V. Degano. (*Ann. Télécommun.*, vol. 12, pp. 436–442; December, 1957.) Optimum dimensions for a probe microphone have been obtained from a study of frequency response curves plotted for various dimensions of the probe tube and cavity. The construction of the probe, experimental response curves and a formula for calculating the frequency response are given.

621.395.61.089.6 1430
Various Methods of Absolute Calibration of Standard Microphones—R. Lehmann. (*Ann. Télécommun.*, vol. 12, pp. 393–408; November, 1957.) 30 references.

621.395.612.4:534.773.2 1431
Technical Fundamentals and New Aspects of the Construction of Miniature Magnetic Microphones—W. O. Holleufer. (*Elektrotech. Z., Edn A*, vol. 79, pp. 533–536; August 1, 1958.) The design and construction of microphones for hearing aids is discussed.

621.395.616 1432
The Electrostatic Uniangular Microphone—H. F. Olson and J. Preston. (*J. Soc. Mot. Pic. Telev. Eng.*, vol. 67, pp. 750–753; November, 1958.) Description of a lightweight microphone comprising an es transducer combined with an acoustic network. It has a uniform frequency response and good directivity.

621.395.623.7 1433
The Response of Loudspeakers near the Principal Resonance—E. Paolini. (*Ann. Télécommun.*, vol. 12, pp. 387–391; November, 1957.) A theoretical study in which the loudspeaker is assumed to be fed by constant-current or constant-voltage signals whose frequency is compared with pressure along the loudspeaker axis.

621.395.623.8:621.396.721 1434
Sound Distribution at the Brussels Exhibition—Martin. (See 1691.)

ANTENNAS AND TRANSMISSION LINES

621.372.2:621.372.826 1435
On the Propagation of Surface Waves over an Infinite Grounded Ferrite Slab—R. L. Pease. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 13–20; January, 1958. Abstract, PROC. IRE, vol. 46, p. 799; April, 1958.)

621.372.8.002.2:621.357.6 1436
The Electroforming of Waveguide Components—P. Andrews. (*Electronic Eng.*, vol. 31, pp. 150–152; March, 1959.) Details are given of a simple acid-copper electroforming process for use in laboratory or small-scale production. The bath, electrical supply and mandrel materials required are described.

621.372.81.09:061.3 1437
Waveguide Transmission—(*Wireless World* vol. 65, pp. 104–105; March, 1959.) A report is given of an IEE Convention on "Long-Distance Transmission by Waveguide" held in London, January 29–30, 1959. Problems associated with the use of the H_{01} mode in circular waveguides and with the single-wire surface-wave system are briefly discussed.

621.372.826:537.226 1438
Excitation of a Transverse Magnetic Surface Wave Propagated on a Dielectric Cylinder—C. Jauquet. (*Ann. Télécommun.*, vol. 12, pp. 217–233; June, 1957.) Detailed theoretical treatment (see 3031 of 1957) with a note of an experimental investigation of the surface-wave characteristics of a polystyrene rod.

621.372.852.323:621.318.134 1439
Resonance Isolator at 70 kMc/s—L. C. Kravitz and G. S. Heller. (PROC. IRE, vol. 47, p. 331; February, 1959.) Describes a precessional-resonance waveguide isolator using an oriented Ba ferrite having an effective internal magnetization of 17,000 G. With an additional external field of 8000 G the isolator gives an insertion loss of 1 db and a reverse loss of 12 db.

621.396.67 1440
Driving Point and Input Admittance of Linear Antennas—T. T. Wu and R. W. P. King. (*J. Appl. Phys.*, vol. 30, pp. 74–76; January, 1959.) "An infinity in the input admittance of linear antennas owing to the use of an idealized delta-function generator is investigated. It is shown that the infinity may be interpreted in terms of an infinite capacitance

between the two halves of the antenna. The conclusion is reached that conventionally used iterative procedures are not invalidated by difficulties with respect to the driving point."

621.396.67:621.315.1:621.396.11.029.45 1441
Power-Line Aerial—Golden, Langmuir, Macmillan and Rusch. (See 1672.)

621.396.67.012.12 1442
On the Fresnel Approximation—R. B. Barrar and C. H. Wilcox. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 43–48; January, 1958. Abstract, PROC. IRE, vol. 46, p. 799; April, 1958.)

621.396.674 1443
Four Simultaneous Transmissions from One Aerial—F. D. Bolt. (*Electronic Eng.*, vol. 31, pp. 168–170; March, 1959.) The antenna is a single slotted cylindrical type which radiates an effective power of 120 kw omnidirectionally on 88.1, 90.3, 92.5 and 94.7 cps. The input voltage swr is not greater than 1.2.

621.396.674.3 1444
Back-Scattering Cross-Section of a Centre-Loaded Cylindrical Antenna—Yueh-Ying Hu. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 140–148; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

621.396.677 1445
The Prolate Spheroidal Antenna: Current and Impedance—C. P. Wells. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 125–128; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

621.396.677.32 1446
End-Fire Echo Area of Long, Thin Bodies—L. Peters, Jr. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 133–139; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

621.396.677.833 1447
An Omnidirectional Vertically Polarized Paraboloid Aerial—E. O. Willoughby and E. Heider. (*Proc. IRE (Australia)*, vol. 19, pp. 554–555; October, 1958.) A preliminary note giving a brief description of the antenna. At 28.7 cm λ the half-power beam width is 6.6°.

621.396.677.833 1448
Wide-Angle Scanning with Microwave Double-Layer Pillboxes—W. Rotman. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 96–105; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

621.396.677.833.2 1449
Surface-Wave Beacon Antennas—R. E. Plummer. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 105–114; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

621.396.677.85 1450
Experimental Test on Some Microwave Configuration Lenses—P. F. Checcacci and V. Russo. (*Alta Frequenza.*, vol. 27, pp. 92–107; April, 1958.) Report on tests carried out with two conflection-refraction lenses and a conflection doublet [see e.g. *J. Opt. Soc. Amer.*, vol. 45, pp. 621–624; August, 1955. (Toraldo di Francia)]. Radiation and wavefront diagrams are given.

621.396.679.1 1451
The Distribution of Lightning Currents in the Earthing Systems of a Radio Mast—W. Griesinger, E. Popp and E. Schulz. (*Elektrotech. Z., Edn A*, vol. 79, pp. 526–529; August 1, 1958.) The protection of telephone cables anchored to radio masts is considered; this can be achieved by enlarging the earthing system, particularly in mountainous regions, and by special screening of the telephone cable.

AUTOMATIC COMPUTERS

681.142 1452
Digital Techniques for Small Computations—Y. Lundh. (*J. Brit. IRE*, vol. 19, pp. 37–44; January, 1959.) A special digital method of computing simple algebraic functions with one to four variables is described and analyzed. The method is particularly suited to division and root extraction.

681.142 1453
Automatic Failure Recovery in a Digital Data Processing System—R. J. Doyle, R. A. Meyer and R. P. Pedowitz. (*IBM. J. Res. Developm.*, vol. 3, pp. 2–12; January, 1959.) A program is described which automatically compensates for computer malfunctions so that recovery from errors may be affected with a negligible loss of operational time.

681.142 1454
Representation, Grouping and Processing of Information in Automatic Data Processing—H. Zschekel. (*Elektrotech. Z., Edn A*, vol. 79, pp. 617–624; September 11, 1958.)

681.142 1455
A Sensing System for Punched Cards or Continuous Punched Foil—S. Morleigh. (*Electronic Eng.*, vol. 31, pp. 140–141; March, 1959.)

681.142 1456
Logic Synthesis of Some High-Speed Digital Comparators—M. Nesenbergs and V. O. Mowery. (*Bell. Sys. Tech. Jour.*, vol. 38, pp. 19–44; January, 1959.) Logical schemes are derived by Boolean algebra methods. Circuits satisfying the synthesis requirements and giving either exact or approximate proportional comparison are described.

681.142 1457
Function Generator for Sines or Cosines—H. Schmid. (*Electronics*, vol. 32, pp. 48–50; January 23, 1959.) Operation of the transistorized unit described is based on the fact that the area under a sine curve varies as a cosine function. Basic components required are a linear pulse-width modulator, an ideal switch (two *p-n-p* transistors connected emitter-to-emitter), an integrator and a sine-wave source.

681.142:537.311.33:546.281.26 1458
An Analogue Multiplier-Divider Using Thyrites—A. A. Maslov. (*Aytomalika i Telemekhanika*, vol. 18, pp. 336–348; April, 1957.) A new analytical method is proposed for determining quadratic elements using thyrite resistors. A description is given of a new multiplier with thyrite units which requires only two operational amplifiers. Experimental results are given.

681.142:621–526 1459
Logic for a Digital Servo System—R. W. Ketchledge. (*Bell. Sys. Tech. Jour.*, vol. 38, pp. 1–17; January, 1959.) A crt beam in a photographic storage system is positioned by comparing a binary address with a digital indication of the present position. Digital servo logic circuitry is described for obtaining the sign and magnitude of the positional error.

681.142:621.318.5 1460
An Electron Analyser of Contact Circuits—V. N. Rodin. (*Aytomalika i Telemekhanika*, vol. 18, pp. 437–443; May, 1957.) A description is given of an apparatus for rapid determination of possible combinations in the operation of a circuit comprising six relays. One of the possible uses of the apparatus is the simplification of the existing circuits by removing the unnecessary contacts.

681.142:621.318.57 1461
The Multipurpose Bias Device: Part 2—The Efficiency of Logical Elements—B. Dunham, D. Middleton, J. H. North, J. A. Sliter and J. W. Weltzien. (*IBM J. Res. Developm.*, vol. 3, pp. 46–53; January. 1959.) "The efficiency of a logical element can be equated with the set of subfunctions it realizes upon biasing or duplication of inputs. Various classes of elements are considered, and optimum or near-optimum examples are presented. Some related areas of study are suggested." Part 1: 38 of 1958 (Dunham).

681.142:621.318.57:538.221 1462
Millimicrosecond Magnetic Gating and Storage Element—D. A. Meier. (*J. Appl. Phys.*, vol. 30, pp. 122–123; January, 1959.) The element consists of a round glass rod which is first chemically plated with a silver conductor and then electrodeposited with an Fe-Ni film. The element has an almost square saturation loop.

681.142:621.318.57:621.318.134 1463
The Laddic—a Magnetic Device for Performing Logic—U. F. Gianola and T. H. Crowley. (*Bell Sys. Tech. Jour.*, vol. 38, pp. 45–72; January, 1959.) The laddic is a ladder-like structure cut from rectangular-hysteresis-loop ferrite. All magnetic paths are flux-limited. By controlling the actual switching path any Boolean function of n variables can be produced.

681.142:621.395.625.3 1464
Tape Recording System Speeds Data Processing—Way Dong Woo. (*Electronics*, vol. 32, pp. 56–68; February 6, 1959.) A PWM tape recording system is described with a capacity of 60,000 digits. The tape is three inches wide and carries 36 channels. The transport mechanism is electronically controlled and can start, stop and reverse within a few milliseconds.

681.142:621.396.962.012 1465
An Analogue Computer for Evaluating Radar Performance—C. C. Willhite and J. W. McIntyre. (*Bell. Lab. Rec.*, vol. 37, pp. 16–19; January, 1959.) Describes briefly the basic design of an analogue computer developed to evaluate the statistical information needed to assess radar tracking performance.

681.142:629.13 1466
Application of Analogue Calculation to Flight Simulators—J. W. Swift. (*Rev. HF, Brussels*, vol. 4, pp. 1–10; 1958.) Computer elements for simulating the reactions resulting from the effects of gyration, pitch and roll are described.

CIRCUITS AND CIRCUIT ELEMENTS

621.314.2:621.372.4 1467
The Transformer as a Two-Terminal Network—W. Klein. (*Arch. elekt. Übertragung*, vol. 12, pp. 133–137; March, 1958.) The equivalent two-terminal networks are derived for various types of transformer.

621.314.2:621.372.51 1468
On Hybrid Transformers—H. O. Friedheim. (*A.T.E. J.* vol. 14, pp. 218–228; July, 1958.) Design formulas are derived from basic assumptions, and the properties and some common uses of these circuit elements are discussed.

621.314.2.073.3:621.318.124:621.374.3 1469
Premagnetization of the Core of a Pulse Transformer by Means of Ferroxdure—H. G.

Bruijning and A. Rademakers. (*Philips Tech. Rev.*, vol. 19, pp. 28–37; July 27, 1957.) Premagnetization to improve the loading of the core of a transformer carrying unidirectional pulse currents is examined theoretically. A practical transformer is described.

621.314.5:621.314.7 1470
High-Power Transistor D.C. Converters—T. R. Pye. (*Electronic Radio Eng.*, vol. 36, pp. 96–105; March, 1958.) Circuits are considered for dc per dc or dc per ac converters using Ge and Si power transistors which can give power outputs of up to 100 watts.

621.318.57:621.318.435 1471
Saturable-Transformer Switches—B. D. Simmons. (*Electronic Radio Eng.*, vol. 36, pp. 82–90; March, 1959.) A switch using cores in a balanced saturable transformer is considered. An on-off impedance ratio adequate for switching magnetic recording heads for reading and writing operations can be obtained. Circuits are described for operation of a matrix selection system with a switching time of a few tens of microseconds.

621.319.4:537.227:621.396.662 1472
Ferroelectrics Tune Electronic Circuits—T. W. Butler, Jr. (*Electronics*, vol. 32, pp. 52–55; January 16, 1959.) Circuits are described in which varying bias is used to change the capacitance of ferroelectric capacitors used as tuning elements.

621.319.4.015.5 1473
Direct-Voltage Instantaneous Breakdown of Oil-Impregnated Paper Capacitors as a Function of Area—D. S. Girling. (*Elect. Commun.*, vol. 35, pp. 83–92; 1958.) The experimental results given show that the variation of mean breakdown voltage with increasing area is represented adequately by Milnor's equation. The coefficient of variation appears to be independent of area but decreases with increasing thickness of dielectric.

621.319.42:621.315.616.98 1474
A Comparison of Wool Wax and Petroleum Jelly as Impregnants for Paper Capacitors—J. S. Dryden and R. J. Meakins. (*Proc. IRE (Australia)*, vol. 19, pp. 551–535; October, 1958.) Results given show that wool wax impregnants give about 10 per cent higher capacitance without any serious loss in performance.

621.372.412.012.8 1475
The Equivalent Circuit of Oscillating Piezoelectric Crystal Rods—J. Tichý. (*Ann. Phys. (Lpz.)*, vol. 1, pp. 219–231; May 20, 1958.) Formulas are derived for calculating the circuit parameters for longitudinal, torsional and flexural oscillations taking account of internal damping and the air gap between electrodes and crystal.

621.372.45 1476
Voltage- and Current-Controlled Negative-Resistance Two-Poles—L. Piglione. (*Alta Frequenza*, vol. 27, pp. 138–152; April, 1958.) The mechanism of voltage and current control in two-pole networks is discussed. Equations for obtaining the equivalent circuits from direct measurements at the network terminals are given.

621.372.5 1477
The Geometrically Simplest Form of Representation of the General Lossy Quadripole—J. de Buhr. (*Arch. elekt. Übertragung*, vol. 12, pp. 127–132; March, 1958.) The transformation discussed is based on a construction of four planes perpendicular to each other in pairs in a non-Euclidean system. It can be represented in a drawing by stereographic projection.

621.372.5 1478
Coupling Coefficients of Ladder Networks with Maximally Flat Amplitude Response—R. A. Waldron. (*J. Brit. IRE*, vol. 19, pp. 63–71; January, 1959.) The coefficients are expressed in terms of the dissipations in the input and output branches, using a generalized theory of Green's method of solution (370 of 1955).

621.372.5 1479
H.F. Wide-Band Electronic Integrator Design—H. Hodara. (*Electronic Ind.*, vol. 17, pp. 96–100; October, 1958.) Compensation for distortion of the integrated waveform due to valve output capacitances can be introduced by the addition of a capacitor in parallel with the integrating-network resistance. An expression is derived for calculating this capacitance for the basic RC integrator and the Miller integrator.

621.372.51 1480
Impedance Converters—F. Molo. (*Alta Frequenza*, vol. 27, pp. 120–137; April, 1958.) The quadripole relations and equivalent circuits of negative-impedance converters are summarized and applied to practical unbalanced converter circuits with valves and transistors.

621.372.55 1481
A Laguerre Function Equalizer—H. Mumford and E. J. Osborne. (*A.T.E. J.*, vol. 14, pp. 196–202; July, 1958.) A waveform corrector is described in which the input signal is successively differentiated and the differentials added to or subtracted from the input, the waveforms being given by Laguerre functions. Results are given for an experimental equalizer which need contain only passive elements.

621.373.4–523.6 1482
Constant-Frequency Oscillators without Stabilized Voltage Supplies—W. Wisotzky. (*Elektronik*, vol. 7, pp. 79–80; March, 1958.) Four valve oscillators controlled by thermistor bridge circuits are described.

621.373.421.13 1483
The Design of Crystal-Controlled Three-Terminal Valve Oscillators—F. Rockstuhl. (*Telefunken Ztg*, vol. 31, pp. 50–58; April, 1958. English summary, pp. 68–69.) Design formulas for the Pierce-Miller and Pierce-Colpitts circuits are derived taking account of the effect of crystal resistance on frequency.

621.373.421.13 1484
Stable, Low-Cost 1-Mc/s Oscillator—J. F. Mercurio, Jr. (*Electronics*, vol. 32, pp. 50–51; February 6, 1959.) Description of a crystal-controlled transistorized oscillator with frequency stability within one part in 10^9 per day at normal room temperatures. Total weight of oven and oscillator is 2.5 lb.

621.373.421.13:621.396.666:621.396.11 1485
Frequency Stepper for Radio Propagation Tests—E. H. Hugenholtz, A. Seljak and A. Towle. (*Electronics*, vol. 32, pp. 44–46; January 23, 1959.) Full circuit details are given of a stepped-frequency exciter unit controlling a pulse transmitter and receiver at widely separated locations. The range 25.05–48.95 mc is covered in 100-kc steps at 1-sec intervals. 100-kc and 1-mc crystals are used as reference-frequency sources, and frequency control is achieved by means of a beam-deflection tube. Transmitter and receiver circuits are briefly described: the transmitter radiates 25-μs pulses with repetition frequency 30 per sec or 15 per sec and output power 10–20 kw.

621.373.421.14:621.385.029.64 1486
A Barkhausen-Kurz Oscillator at Centimetre Wavelengths—E. M. Boone, M. Uenohara and D. T. Davis (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 196–205; July, 1958. Abstract, PROC. IRE, vol. 46, pp. 1890–1891; November, 1958.)

621.373.421.14:621.396.962.23 1487
Dual-Cavity Microwave Discriminator—M. Rudin, R. E. Shafer and B. W. Baker. (*Electronics*, vol. 32, pp. 74, 76; January 16, 1959.) Intended for stabilizing reference klystron oscillators used in Doppler-shift radar systems. Tuning range is ± 50 mc thermal drift 1 part in 10^7 per °F, and discriminator sensitivity 1.5 v per mc.

621.373.431 1488
The Generation of Extremely Steep Pulse Edges in Multistage Nonlinear Amplifiers—G. Kohn. (*Arch. elekt. Übertragung*, vol. 12, pp. 109–118; March, 1958.) The pulse generator described incorporates three transformer-coupled amplifier stages for sharpening the multivibrator pulses; it can supply 100-v 50-μs pulses with a rise time <3 mμs into a 60-Ω load.

621.373.52:621.376.3 1489
Transistorized F.M. Oscillator—P. W. Wood. (*Electronics*, vol. 32, p. 64; January 30, 1959.)

621.375.1.018.424 1490
The Amplification of Very Wide Frequency Bands—K. H. Fischer and G. Daisenberger. (*Elektrotech Z., Edn A.*, vol. 79, pp. 625–632; September 11, 1958.) Various techniques for amplification in bandwidths exceeding 100 mc are discussed and the suitability of cascade and distributed amplifiers is investigated. Direct and indirect methods of delay-line equalization are outlined and details are given of a seven-stage distributed amplifier with 10-db gain over a 125-mc band.

621.375.121 1491
Wide-Band Amplifier Design Data—R. H. Engelmann. (*Electronics*, vol. 32, pp. 43–49; February 6, 1959.) Design data are tabulated for three basic types of coupling, RC, shunt-peaked and series-peaked. Gain is calculated using a series of approximations taking account of the gain reduction factor for a number of stages.

621.375.121.2 1492
Extended-Range Distributed-Amplifier Design—J. J. Eichholz, C. F. Nelson and G. T. Weiss. (*Rev. Sci. Instr.*, vol. 30, pp. 1–6; January, 1959.) "A distributed amplifier employing a straight-wire transmission line is described. The amplifier has a gain of 15 ± 3 db from 10 to 400 mc, and input and output impedances of 50 Ω. Detailed electrical and mechanical design considerations are included."

621.375.132.3.029.3 1493
An Inexpensive Ultralinear Output Stage—I. F. Barditch. (*Electronic Ind.*, vol. 17, p. 89; October, 1958.) A circuit is described which uses two cathode followers in place of a tapped output transformer.

621.375.23:621–52 1494
Operational Amplifier without a Stabilized Power Supply—V. M. Evseev. (*Aytomalika i Telemekhanika*, vol. 18, pp. 427–436; May, 1957.) A new operational amplifier is proposed in which two parallel circuits for low and high frequencies are used, with a summing amplifier and two feedback circuits. The theory of the amplifier is discussed and some experimental results are given. For a mains voltage variation of ± 10 v, the output voltage of the amplifier varies by 16 mv with a drift rate of 45 μv sec.

621.375.3 1495
On the Theory of a Half-Wave Magnetic

Amplifiers—R. A. Lipman and I. B. Negnevitskiĭ. (*Aytomalika i Telemekhanika*, vol. 18, pp. 349–370 and 449–465; April and May, 1957.) A detailed theoretical analysis is given of an amplifier proposed by Ramey (see 3503 and 3507 of 1953). Experimental results confirm the theoretical conclusions.

621.375.4 1496
Differential Amplifier Features D.C. Stability—W. T. Matzen and J. R. Biard. (*Electronics*, vol. 32, pp. 60–62; January 16, 1959.) Drift in transistorized amplifiers is analyzed and circuits for reducing drift are described for a particular amplifier. A 12-h test showed the equivalent input drift to be less than 60 μv from 70° to 80°C.

621.375.4(083.57) 1497
Nomographs for Designing Transistor Narrow-Band Amplifiers—L. M. Krugman. (*Electronic Ind.*, vol. 17, pp. 78–81; October, 1958.)

621.375.4.024 1498
Transistor Amplifiers for D.C. Signals—H. Kemhadjian. (*Mullard Tech. Commun.*, vol. 4, pp. 162–172; December, 1958.) Basic direct-coupled and chopper-type amplifiers are examined and compared.

621.375.4.029.3:534.6 1499
A Low-Noise Transistor Amplifier for Acoustic Measurements—E. R. Hauri. (*Tech. Mitt. PTT*, vol. 36, pp. 142–144; April 1, 1958.) The portable equipment described has a gain of about 60 db and a frequency range 30 cps–15 kc with noise output 3.5 db above the theoretical minimum.

621.375.9:538.569.4.029.6 1500
The Maser: a New Form of Microwave Oscillator—C. M. Cade. (*J. Telev. Soc.*, vol. 8, pp. 509–511; October–December, 1958.) A short review of the principles of operation of molecular-beam and solid-state masers.

621.375.9:538.569.4.029.6 1501
Small-Signal Analysis of Molecular-Beam Masers—J. C. Helmer. (*J. Appl. Phys.*, vol. 30, pp. 118–120; January, 1959.) A perturbation calculation gives the resonance polarization of a molecule in an electric field as a function of time. An analysis is then made of maser operation with a divergent univelocity beam.

621.375.9:538.569.4.029.6 1502
Three-Level Solid-State Maser—S. M. Bergmann. (*J. Appl. Phys.*, vol. 30, pp. 35–36; January, 1959.) The maximum values of the real and imaginary components of the paramagnetic susceptibility of a three-level solid-state maser are calculated. General expressions for the gain and bandwidth of a traveling-wave maser are given.

621.375.9.029.64:621.3.011.23 1503
Low Noise in Solid-State Parametric Amplifiers at Microwave Frequencies,—W. E. Danielson. (*J. Appl. Phys.*, vol. 30, pp. 8–15; January, 1959.) "The principles of parametric amplification are described through the use of simple low-frequency electrical circuits and their mechanical analogs. Extension of these principles to low-noise amplification at microwave frequencies is made in a qualitative way which emphasizes the physical processes involved. Amplification is only achieved when energy is transferred from a microwave oscillator or pump to the signal frequency, and it is shown why such a transfer may take place in circuits exhibiting variable capacitance or inductance but not in circuits where only a resistance is varied. Major noise sources are discussed and the special role of the image or idler frequency is noted. Finally, experimental data on four different types of parametric amplifier (three using semiconductor diodes and one using ferrite) are given."

621.376.3:621.3.018.78 1504
Calculation of Harmonic Distortion in Sinusoidal Frequency Modulation. Cases of a Waveguide of Any Cross-Section and an Amplification State with a Tuned Transformer—L. Robin. (*Ann. Télécommun.*, vol. 12, pp. 415–418; December, 1957.) See also 1282 of 1953 (Robin).

GENERAL PHYSICS

537.212:537.291 1505
Potential of an Electrostatic Field and Trajectories of Charged Particles—G. Sacerdoti and H. Toschi. (*Alta Frequenza*, vol. 27, pp. 108–119; April, 1958.) A procedure is described for calculating the electric potential in the proximity of the path of a charged particle.

537.222:621.314.63 1506
Solutions for the Static Junction—L. Gold. (*J. Electronics Control*, vol. 5, pp. 427–431; November, 1958.) Discussion of certain classes of solution of the nonlinear differential equation for the potential distribution near a *p-n* junction. An inverse series solution is developed which is appropriate for diverse impurity distributions.

537.311.1 1507
A New Method for the Evaluation of Electric Conductivity in Metals—S. F. Edwards. (*Phil. Mag.*, vol. 3, pp. 1020–1031; September, 1958.) A method is developed for evaluating the closed formal expressions for electrical conductivity which have recently been developed. See e.g. 1105 of 1958 (Kohn and Luttinger) and 2361 of 1958 (Greenwood).

537.534.8 1508
Secondary Positive Ion Emission from Metal Surfaces—R. C. Bradley. (*J. Appl. Phys.*, vol. 30, pp. 1–8; January, 1959.) Secondary positive ions ejected from surfaces of Mo, Ta, and Pt under bombardment by inert gas ions of low energy (<1000 ev) have been studied in high vacuum using a mass spectrometer with a 6 inch radius of curvature and a 60° sector field.

537.56 1509
Current/Voltage Behaviour in a Plasma—L. Gold. (*J. Electronics Control*, vol. 5, pp. 432–434; November, 1958.) An exact solution for the current/voltage relation in a planar diode filled with a uniform plasma.

537.56:537.122 1510
Electron Recombination and Negative Bands in Afterglowing Active Nitrogen—H. H. Brömer and V. Stille. (*Optik*, vol. 15, pp. 382–388; June, 1958.) The emission of negative bands in the auroral afterglow of nitrogen is interpreted as being due to excitation of molecular ions; this is supported by recent measurements of the decay of light intensity of these bands.

537.56:538.56 1511
A Note on the Confinement of a Plasma by R.F. Fields—E. S. Weibel. (*J. Electronics Control*, vol. 5, pp. 435–538; November, 1958.) A rigorous derivation of certain results previously obtained by Boot *et al.* (3411 of 1958) by inferior methods.

537.56:538.561 1512
Microwave Emission from High-Temperature Plasmas—D. B. Beard. (*Phys. Rev. Lett.*, vol. 2, pp. 81–82; Feb. 1, 1959.) Energy losses from cyclotron radiation are concluded to be negligible for plasma temperatures less than 100 kev and probably for those greater than 100 kev. Emission at the fundamental frequency and first few harmonics is detectable, and measurement of the relative intensities offers a means of determining the plasma temperature.

537.56:538.566 1513
Excitation of Oscillations in a Plasma Layer—M. Sumi. (*Phys. Rev. Lett.*, vol. 2, pp. 37–39; January 15, 1959.) Development of a linearized theory of plasma oscillations excited by an electron beam injected into a uniform plasma.

538.3:535.13 1514
Laws of Magnetism and of Static Electricity in Any Given Frame of Reference—H. Arzeliès and J. Henry. (*Compt. rend. Acad. Sci., Paris*, vol. 247, pp. 815–817; September 15, 1958.) A study of Maxwell's equations in terms of the general theory of relativity is made as a preliminary to attempting to solve practical electrical problems.

538.566:535.42 1515
On the Diffraction of Electromagnetic Waves at Infinitely Thin Ideally Conducting Flat Screens—G. A. Grinberg and Yu. V. Pimenov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2326–2339; October, 1957.) A new method is described based on the solution of two independent equations. As an example, the case of diffraction of a wave at an infinitely thin conducting disk is discussed.

538.566:535.42 1516
Electromagnetic Diffraction by Dielectric Strips—D. C. Stickler. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 148–151; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

538.566:535.43 1517
An Analytical Study of Scattering by Thin Dielectric Rings—L. L. Philipson. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 3–8; January, 1958. Abstract, PROC. IRE, vol. 46, pp. 798–799; April, 1958.)

538.566:535.43 1518
A Statistical Model for Forward Scattering of Waves off a Rough Surface—L. M. Spetner. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 88–94; January, 1958. Abstract, PROC. IRE, vol. 46, p. 800; April, 1958.)

538.566:535.43 1519
Light Scattering by Small Particles [Book Review]—H. C. van de Hulst. Publishers: John Wiley and Sons, New York, N. Y., and Chapman and Hall, London, Eng., 1957, 470 pp., 96s. (*Nature, London*, vol. 182, pp. 1470–1471; November 29, 1958.)

GEOPHYSICAL AND EXTRATERRESTRIAL PHENOMENA

523.164+621.396.93 1520
Propagation of Electromagnetic Waves, Radio Location and Radio Astronomy—Roessler. (See 1581.)

523.164:523.75 1521
Ionization of the Upper Atmosphere by Low-Energy Charged Particles from a Solar Flare—H. Leinbach and C. G. Reid. (*Phys. Rev. Lett.*, vol. 2, pp. 61–63; January 15, 1959.) Discussion of recordings made at Thule, Greenland, and Barrow and College, Alaska, of cosmic-noise absorption at 27.6 mc at the time of a class-3 solar flare on July 29, 1958.

523.164.3 1522
Radio Observations of the Planet Jupiter—K. L. Franklin and B. F. Burke. (*J. Geophys.*

Res., vol. 63, pp. 807–824; December, 1958.) Details are given of observations outlined previously (*Astrophys. J.*, vol. 61, p. 177, May, 1956; and *Carnegie Inst. of Wash. Year Book*, no. 55, pp. 74–76, 1955/1956) together with unpublished information from earlier observations in June, 1954. Correlation of the observations with rotation, polarization, and frequency characteristics is discussed. Most of the radio noise bursts were strongly circularly polarized, and the spectrum does not appear to be continuous over the frequencies observed. Critical reflections by an ionosphere around Jupiter are discounted.

523.165:523.74 1523

Cosmic-Ray Intensity Variations during Two Solar Cycles—S. E. Forbush. (*J. Geophys. Res.*, vol. 63, pp. 651–669; December, 1958.) From ionization-chamber data the decrease of cosmic-ray intensity from its maxima (near sunspot minima) is shown to lag a year or more behind the increase of solar activity following sunspot minima. The variability of daily mean values was particularly great in 1957.

523.165:550.38 1524

Cosmic Rays in the Earth's Magnetic Field—P. Rothwell. (*Phil. Mag.*, vol. 3, pp. 961–970; September, 1958.) Discrepancies between center dipole predictions using the Störmer equation and experimental observations of cosmic-ray intensities and cutoff phenomena are attributed to differences between the earth's real field and the dipole approximation to it, rather than to distortion of the earth's outer magnetic field by ionized interplanetary matter. An empirical expression for the cutoff phenomena is deduced which is in good agreement with experimental results over a wide range of latitude and longitude.

523.3:621.396.9 1525

Comparison of Measured and Computed Values of the Rapid Fading Rate of Ultra-High-Frequency Signals Reflected from the Moon—S. J. Fricker, R. P. Ingalls, W. C. Mason and M. L. Stone. (*Nature* (*London*), vol. 182, pp. 1438–1439; November 22, 1958.) Observations made in U.S.A. in August, 1957, during a bistatic moon reflection experiment carried out at 412.85 mc are reported. They show good agreement with values calculated from the effective libration rate of the moon.

523.5:551.510.535 1526

Meteors in the Ionosphere—L. A. Manning and V. R. Eshleman. (Proc. IRE, vol. 47, pp. 186–199; February, 1959.) The nature of radio reflections from the trails of ionization produced by meteors is reviewed and the principal use of meteors as research tools are described. Some further directions in which meteor research may be pursued are suggested.

523.5:621.396.11:551.510.535 1527

Concerning Booker's Theory of Meteoric Reflections—L. A. Manning and V. R. Eshleman. (*J. Geophys. Res.*, vol. 63, pp. 737–739; December, 1958.) The assumption of small-scale ionospheric turbulence [see e.g. 1417 of 1957 (Booker and Cohen)] conflicts with many known facts about meteor echoes, such as the persistence of aspect sensitivity for as long as ten seconds and the known variation with time of the angular correlation function.

523.53:621.396.11 1528

Electromagnetic Scattering by Low-Density Meteor Trails—Brysk. (See 1665.)

523.746 1529

The Zurich Sunspot Number and its Variations for 1700–1957—E. J. Chernosky and M. P. Hagan. (*J. Geophys. Res.*, vol. 63, pp. 775–788; December, 1958.) Monthly and auroral mean values of relative sunspot number are tabulated for 1749–1957. Estimates of annual values by Wolf for the period 1700–1759 are also given, together with derived data.

523.75:523.72 1530

Radiation and Particle Precipitation upon the Earth from Solar Flares—L. Biermann and R. Lüst. (Proc. IRE, vol. 47, pp. 209–210; February, 1959.) A brief survey in which the energies of these emissions are estimated and their effects on the ionosphere discussed.

550.380.2 1531

Centenary of Melbourne-Toolangi Magnetic Observatory—J. C. Dooley. (*J. Geophys. Res.*, vol. 63, pp. 731–735; December, 1958.) Brief history of the observatory since 1958.

550.385 1532

Possible Causes of Geomagnetic Fluctuations Having a Six-Second Period—F. B. Daniels. (*Nature* (*London*), vol. 182, p. 1439; November 22, 1958.) The fluctuations described by Duffus *et al.* (3441 of 1958) may be due to small oscillations of the earth's crust ("microseisms") or, more probably, atmospheric oscillations with the same period ("microbaroms").

550.385:551.510.535 1533

The Diurnal Variation of Irregular Geomagnetic Fluctuations: Part 2—S. B. Nicholson and O. R. Wulf. (*J. Geophys. Res.*, vol. 63, pp. 803–806; December, 1958.) "Using the eight daily K numbers (three-hour-range indexes) for six observatories in moderately low latitudes and fairly well distributed in longitude, a universal-time component of the daily variation of irregular geomagnetic fluctuations having an apparently significant amplitude in the yearly average has been found in the data for the nine years 1940–1948. It is suggested that a portion of magnetic disturbance may be produced by dynamo action in the ionosphere, and give rise to this yearly-average universal-time component." For Part 1, see 1403 of 1956.

550.385.2:525.624 1534

Lunar Geomagnetic Tides at Kodaikanal—K. S. Raja Rao and K. R. Sivaraman. (*J. Geophys. Res.*, vol. 63, pp. 727–730; December, 1958.) Tschu's method (636 of 1950) has been applied to the calculation of the lunar semi-diurnal variation of the horizontal intensity of the earth's magnetic field at Kodaikanal. The solar diurnal variation is also determined.

550.385.4 1535

Time Constants in the Geomagnetic Storm Effect—C. O. Hines and L. R. O. Storey. (*J. Geophys. Res.*, vol. 63, pp. 671–682; December, 1958.) An estimate is made of the delay between formation of a ring current round the earth and the occurrence of a geomagnetic storm at ground level. Parker (1422 of 1957) has estimated the delay as several months; but by taking proper account of the fluidity of the medium and the presence of the main geomagnetic field the delay is found to be small enough to be consonant with the ring-current theory of geomagnetic storms.

550.385.4 1536

Inadequacy of Ring-Current Theory for the Main Phase of a Geomagnetic Storm—E. N. Parker. (*J. Geophys. Res.*, vol. 63, pp. 683–689; December, 1958.) There appears to be insufficient dissipation to allow significant diffusion, during a magnetic storm, of the magnetic fields in the vicinity of the earth. A ring-current field can therefore only increase the horizontal component of the geomagnetic field and cannot account for the main phase of a geomagnetic storm.

550.385.4 1537

Studies on Geomagnetic Storm in relation to Geomagnetic Pulsation—Y. Kato and T. Watanabe. (*J. Geophys. Res.*, vol. 63, pp. 741–756; December, 1958.) For the 27-day recurring geomagnetic storm (M type), the "cone of avoidance" model of Pecker and Roberts (1970 of 1955) is supported by both geomagnetic and cosmic-ray data. For the sporadically occurring storm (S type) a shock front in interplanetary space may be responsible for the sudden commencement. An exhaustive study should be made to determine whether the sudden commencement is only associated with the S type. The storm-time variation of the geomagnetic pulsation should also be measured during world-wide storms to aid the study of the shock wave.

550.389.2 1538

The International Geophysical Year—L. V. Berkner. (Proc. IRE, vol. 47, pp. 133–136; February, 1959.) The organization which made possible the large international co-operative research effort is described and arrangements for collecting and storing the observational data are outlined.

550.389.2 1539

The Day-to-Day Coordination of I.G.Y. Observations—A. H. Shapley. (Proc. IRE, vol. 47, pp. 323–327; February, 1959.) In addition to regular observational programs, the IGY included special series of observations made during outstanding solar and geophysical events. The organization of these series and the necessary ancillary communication facilities are described briefly.

550.389.2 1540

The Earth and its Environment—S. Chapman. (Proc. IRE, vol. 47, pp. 137–141; February, 1959.) A general outline of the many fields of investigation included in the IGY program of observations. Particular attention is given to the earth's atmosphere and the flow of heat through it from the hot interplanetary gas.

550.389.2:629.19 1541

Motion of a Satellite around an Unsymmetrical Central Body—R. R. Newton. (*J. Appl. Phys.*, vol. 30, pp. 115–117; January, 1959.) If a central body does not have an inversion center, the eccentricity of a satellite orbit varies periodically, with low frequency and large amplitude. Details are worked out for a central body composed of a large spherical mass and a small point mass contained somewhere within it.

530.389.2:629.19 1542

Change of Inclination of a Satellite Orbit—C. H. Bosanquet. (*Nature* (*London*), vol. 182, p. 1533; November 29, 1958.) Comment on 792 of March (Merson and King-Hele).

550.389:2:629.19 1543

Irregularities of Satellite Drag and Diurnal Variations in Density of the Air—G. V. Groves. (*Nature* (*London*), vol. 182, pp. 1533–1534; November 29, 1958.) The theory is applied to satellites 1957β, 1958δ1 and 1958δ2.

550.389.2:629.19 1544

Moon Rocket Tracking—(*Nature* (*London*), vol. 182, p. 1413; November 22, 1958.) A 108-mc interferometer situated at Lasham, Hampshire, was used to track the third American moon rocket on November 8, 1958. A satisfactory record was obtained from 0747 to 0801 GMT.

550.389.2:629.19 1545

Progress of the Russian Earth Satellite Sputnik III (1958δ)—D. G. King-Hele. (*Nature* (*London*), vol. 182, pp. 1409–1411; November 22, 1958.) Orbital data, based chiefly on optical observations, are given for the instrument-carrying vehicle 1958 δ2 and its rocket 1958 δ1.

550.389.2:629.19 1546

The "Explorers"—W. von Braun. (*Engineer* (*London*), vol. 206, pp. 372–375; September 5, 1958.) Extracts from a paper presented at the congress of the International Astronautical Federation, Amsterdam, 1958. Details are given of the rocket firing procedure and satellite instrumentation as well as the tracking system used during the launching of the Explorer satellites.

550.389.2:629.19 1547

Instrumenting the Explorer I Satellite—H. L. Richter, Jr., W. Pilkington, J. P. Eyrand, W. S. Shipley and L. W. Randolph. (*Electronics*, vol. 32, pp. 39–43; February 6, 1959.) A description is given of the 10-mw PM and 60-mw AM transistorized transmitters operating on 108 and 108.3 mc respectively. Total power consumption was 5 mw obtained from four mercury-type cells. Information was transmitted on skin temperature, nose cone temperature, meteorite counts and impacts, and cosmic rays. Details are also given of the test program for the completed apparatus.

550.389.2:629.19:551.510.535 1548

Earth-Satellite Observations of the Ionosphere—W. W. Berning. (Proc. IRE, vol. 47, pp. 280–288; February, 1959.) The various methods of deriving integrated electron content below a satellite are critically reviewed. Although the methods are theoretically capable of giving information of the diurnal, seasonal and latitude variations of content, interpretation of the measurements is difficult because all these variations are present simultaneously; hence some assumptions about one or two of the variables must be made in order that the third one may be studied.

550.389.2:629.19:551.510.535 1549

Investigation of the Ionosphere Using Signals from Earth Satellites—E. Woyk (Chvojková). (*Nature* (*London*), vol. 182, pp. 1362–1363; November 15, 1958.) Possible effects of the ionosphere on radio signals from artificial earth satellites are discussed with reference to theoretical results noted earlier (3085 of 1958).

550.389.2:629.19:551.510.535 1550

Exploration of the Upper Atmosphere with the Help of the Third Soviet Sputnik—V. I. Krassovsky. (Proc. IRE, vol. 47, pp. 289–296; February, 1959.) The instruments carried are described and some of the preliminary results of observations are given. Up to 250 km the principal ionospheric constituent is nitric oxide; above this height ions of atomic oxygen and nitrogen become more important. Electron density falls off slowly above the F region maximum. Positive-ion density at a height of 250 km is about 5×10^5 ions/cm^3, *i.e.* about half the corresponding electron density. The number of collisions with micrometeorites at heights of 150–300 km is 50/m^2/sec.

551.51 1551

The Constitution and Composition of the Upper Atmosphere—M. Nicolet. (Proc. IRE, vol. 47, pp. 142–147; February, 1959.) A survey of the observational data and the theoretical problems involved. Dissociation of molecular O_2 and N_2, diffusion in the thermosphere, and the conduction of heat through the atmosphere are discussed.

551.510.535 1552

The Distribution of Electrons in the Ionosphere—J. O. Thomas. (Proc. IRE, vol. 47, pp. 162–175; February, 1959.) The methods of deriving $N(h)$ profiles are reviewed with particular emphasis on those which include the effects of the earth's magnetic field. Attention is drawn to the use of the extraordinary ray for estimating the electron density below the peak of the E layer. Some results are given of typical diurnal, seasonal, solar-cycle and latitude variations in the electron-density distribution. 92 references.

551.510.535 1553

The Normal D Region of the Ionosphere—J. J. Gibbons and A. H. Waynick. (Proc. IRE, vol. 47, pp. 160–161; February, 1959.) A discussion of low-frequency sounding of the lower ionosphere indicating the radio transmission characteristics to be satisfied. It is suggested that recent measurements of parameters, such as reaction rates, will provide an improved model of the D layer.

551.510.535 1554

The Normal E Region of the Ionosphere—E. V. Appleton. (Proc. IRE, vol. 47, pp. 155–159; February, 1959.) An outline of the structure and behavior of the E layer with particular emphasis on how it differs from an ideal Chapman layer.

551.510.535 1555

The Normal F Region of the Ionosphere—D. F. Martyn. (Proc. IRE, vol. 47, pp. 147–155; February, 1959.) A review which includes comments on the physical conditions of the layer as determined from rocket and satellite observations, Bradbury's hypothesis, "spread-F" and radio-star scintillations.

551.510.535 1556

Motions in the Ionosphere—C. O. Hines. (Proc. IRE, vol. 47, pp. 176–186; February, 1959.) The theoretical factors involved in the interpretation of observational data are discussed. Particular attention is given to tidal motions and the need for theoretical advances in studies of drifts, scintillations, auroral forms, turbulence and large-scale travelling disturbances.

551.510.535 1557

Horizontal Drift Measurements in the Ionosphere near the Equator—N. J. Skinner, J. Hope and R. W. Wright. (*Nature* (*London*), vol. 182, pp. 1363–1365; November 15, 1958.) Drift of the E and F layers has been measured regularly at Ibadan, Nigeria, by the spaced-receiver method. The westward daytime drift velocity in the F layer is about 105 m/s.

551.510.535 1558

The Interpretation of Night-Time Low-Frequency Ionograms—J. M. Watts. (*J. Geophys. Res.*, vol. 63, pp. 717–726; December, 1958.) Two types of retardation of the extraordinary ray on passing through a region whose critical frequency is below the gyro-frequency are discussed. One is observed near the critical frequency of the ordinary ray and the other near the gyro-frequency. Information about the total number and distribution of electrons below the F layer can be deduced from them.

551.510.535 1559

Rocket Observations of the Ionosphere—H. Friedman. (Proc. IRE, vol. 47, pp. 272–280; February, 1959.) A review of the electron-density profiles obtained at Fort Churchill and at White Sands. A comparison of similar data obtained in Russia up to 200 km is made. The effects of polar blackouts and of flares are discussed with particular reference to the nature of the solar ionizing radiation. Comments are also made on the radiation which can be detected at night, interplanetary hydrogen and the electron density in interplanetary space.

551.510.535 1560

Summer-Day Auroral-Zone Atmospheric-Structure Measurements from 100 to 210 Kilometres—R. Horowitz and H. E. LaGow. (*J. Geophys. Res.*, vol. 63, pp. 757–773; December, 1958.) Density and pressure determined during a rocket flight at 1600 CST, July 29, 1957, at Manitoba, Canada, are compared with earlier measurements.

551.510.535(98) 1561

Polar E_s—R. Penndorf and S. C. Coroniti—(*J. Geophys. Res.*, vol. 63, pp. 789–802; December, 1958.) Published ionosonde data are analyzed over the period 1954–1957 and show three distinct types of E_s for north polar stations, each type occurring in a particular geomagnetic zone. A strong correlation between E_s and magnetic activity existing along the auroral belt points to the influence of corpuscular radiation.

551.510.535:523.165 1562

Abnormal Ionization in the Lower Ionosphere Associated with Cosmic-Ray Flux Enhancements—D. K. Bailey. (Proc. IRE, vol. 47, pp. 255–266; February, 1959.) Two separate abnormalities in ionization were recognizable during the great solar event of February 23, 1956: the "early effects" observed at the time of the sudden cosmic-ray enhancement, and the "late effects" which reached a maximum an appreciable time later. A difference in composition between streams of solar particles of cosmic-ray energies and ordinary cosmic rays is postulated to explain the former effect, while the latter is explained in terms of ionization at heights of 30–110 km produced by the passage or stopping of solar particles, predominantly protons. The absence of auroral and magnetic effects is consistent with these explanations. A provisional evaluation is also made of the coefficient of collisional attachment of electrons from negative ions and the negative-ion/electron ratio and effective recombination coefficient at night between 30 and 40 km.

551.510.535:550.385.4 1563

The F Region during Magnetic Storms—K. I. Maeda and T. Sata. (Proc. IRE, vol. 47, pp. 232–239; February, 1959.) Magnetic storms are investigated using the variation of f_0F_2 and h_pF_2 over a wide range of latitude. It is shown that ionization drift theory in association with the dynamo theory is satisfactory in explaining the observed variations.

551.510.535:621.3.087.4 1564

Automatic Sweep-Frequency Ionosphere Recorder, Model C-4—J. N. Brown. (Proc. IRE, vol. 47, pp. 296–300; February, 1959.) A description of an improved equipment for use during the IGY. In addition to the "virtual-height" frequency records, time-lapse motion pictures are taken.

551.510.535:621.3.087.4 1565

The I.G.Y. Three-Frequency Back-Scatter Sounder—A. M. Peterson, R. D. Egan and D. S. Pratt. (Proc. IRE, vol. 47, pp. 300–314; February, 1959.) The equipment consists of three transmitters operating at 12, 18 and 30 mc, each coupled to its own horizontal Yagi antenna on a single rotating pole, and by a TR switch to a receiver whose tuning is interlocked with the transmitter. A camera records the plan-position displays for the three frequencies together with a short-range display. Preliminary results from 13 stations in polar, temperate and equatorial regions are discussed. Phenomena reported include sporadic-E movements, tilted-F-layer propagation, large irregularities in the F layer and echoes from field-aligned ionization.

551.510.535:621.087.4:523.164 1566

The Riometer—a Device for the Continuous Measurement of Ionospheric Absorption—C. G. Little and H. Leinbach. (Proc. IRE, vol. 47, pp. 315–320; February, 1959.) A description of an instrument for the measurement of

ionospheric absorption at high latitudes during the IGY, using the cosmic-noise method (see 1152 of 1958). The circuit details of this self-balancing equipment are given and its advantages over the system of total-power measurement are discussed.

551.593.9 1567
The Night Airglow—F. E. Roach. (PROC. IRE, vol. 47, pp. 267–271; February, 1959.) "A phenomenological description of the night airglow is presented, reviewing the historical background, and what is known about height, temporal and spatial variations in intensity, and movements. The very important relationship to aurora and evidence for latitude-seasonal effects are examined."

551.594.5 1568
Auroral Phenomena—E. N. Parker. (PROC. IRE, vol. 47, pp. 239–244; February, 1959.) Present knowledge of the formation of the aurora is summarized. Mechanisms of particle acceleration are considered, and it is emphasized that there is no consistent theory of auroral phenomena. 37 references.

551.594.5 1569
A Man-Made or Artificial Aurora—A. L. Cullington. (*Nature (London)*, vol. 182, pp. 1365–1366; November 15, 1958.) An auroral display with which were associated radio fade-outs and a magnetic storm was observed at Apia (13°48′S., 171°46′W) on August 1, 1958. These phenomena were probably due to the explosion of a nuclear bomb over Johnston Island on the same date.

551.594.5:550.385 1570
Auroral Ionization and Magnetic Disturbances—B. Nichols. (PROC. IRE, vol. 47, pp. 245–254; February, 1959.) The literature on radio studies of the aurora, the relation between aurora and magnetic storms, and the movements of the ionosphere and auroral forms is coordinated (56 references). An average density of 5×10^5 electrons/cm^3 is sufficient to explain normal radar echoes. Magnetic disturbances are closely related to ionization and luminosity of the aurora. Magnetic variations are also associated with increases in the speeds of motion of the ionization.

551.594.5:621.396.11 1571
Radio Echoes from Auroral Ionization Detected at Relatively Low Geomagnetic Latitudes—Leadabrand and Peterson. (See 1670.)

551.594.5:621.396.11 1572
The Geometry of Auroral Communications—Leadabrand and Yabroff. (See 1671.)

551.594.5:621.396.96 1573
U.H.F. Auroral Radar Observations—B. C. Blevis. (*J. Geophys. Res.*, vol. 63, pp. 867–868; December, 1958.) Describes auroral Doppler spectra obtained at Ottawa with bistatic radars operating at 488 and 944 mc 10-kw CW klystron amplifiers with 28- and 60-foot parabolic reflectors were used, with transmitter-receiver separations of 19 and 100 km. Echoes indicating cross sections of several thousand square meters were obtained on occasions at 944 mc.

551.594.5:621.396.96 1574
A Low-Power V.H.F. Radar for Auroral Research—R. S. Leonard. (PROC. IRE, vol. 47, pp. 320–322; February, 1959.)

551.594.6 1575
The Very-Low-Frequency Emissions Generated in the Earth's Exosphere—R. M. Gallet. (PROC. IRE, vol. 47, pp. 211–231; February, 1959.) Types of noise other than whistlers have been examined using high resolution spectrograms which show the frequency distribution as a function of time. Most of these noises are excited in the exosphere by streams or bunches of high-speed ionized particles trapped in the earth's magnetic field. The excitation mechanism is similar to that of a traveling-wave valve. Most of the observations require that particle velocities be about 10,000 km. A model in which the ratio of electron density to magnetic field strength is almost constant along a line of force in the exosphere seems to be indicated by several types of noise.

551.594.6 1576
Atmospheric Whistlers—R. A. Helliwell and M. G. Morgan. (PROC. IRE, vol. 47, pp. 200–208; February, 1959.) The historical background of the discovery of whistlers and the development of an adequate theoretical exploration of their behavior are reviewed. The program of study during the IGY is described and some examples of results obtained are presented and discussed.

551.594.6 1577
Path Combinations in Whistler Echoes—M. G. Morgan, H. W. Curtis and W. C. Johnson. (PROC. IRE, vol. 47, pp. 328–329; February, 1959.) A note describing groups of whistler echoes recorded at Unalaska (50° geomagnetic latitude) and explaining them in terms of a combination of alternative propagation paths and multiple trips over each path.

551.594.6 1578
A Note on Whistler Propagation in Regions of Very Low Electron Density—O. K. Garriott. (*J. Geophys. Res.*, vol. 63, pp. 862–865; December, 1958.) Calculations made on a model ionosphere indicate that nose whistlers may exist, although attenuation may prevent their observation.

551.594.6:523.75 1579
A 27-kc/s Sudden Enhancement of Atmospherics Anomaly—W. A. Feibelman. (*J. Geophys. Res.*, vol. 63, p. 866; December, 1958.) On May 1, 1958, two "anomalous" solar flares caused a sharp drop in the 27-kc signal level recorded at Pittsburgh, Pa., instead of the usual enhancement. Enhancements were recorded elsewhere.

551.594.6:621.396.821 1580
Study of the Atmospheric Radio Noise at 27 and 100 kc/s at Delhi—D. K. Sachdev. (*J. Sci. Indust. Res.*, vol. 17A, pp. 262–270; July, 1958.) Preliminary survey of observations extending over a year, with particular reference to sudden enhancement effects.

LOCATION AND AIDS TO NAVIGATION

621.396.93+523.164 1581
Propagation of Electromagnetic Waves, Radio Location and Radio Astronomy—E. Roessler. (*Electrotech. Z., Edn A*, vol. 79, pp. 737–740; October 1, 1958.) Review of recent developments. 49 references.

621.396.93:621.396.677.83 1582
The Application of Metallic Reflectors for Purposes of Location—G. Megla. (*Hochfreq. und Elektroak.* vol. 66, pp. 106–115; January, 1958.) The use of stationary and rotating plane mirrors for radio beacons and other navigational aids is described. For English version see IRE 1957 WESCON CONVENTION RECORD, vol. 1, Part 10, pp. 29–40.

621.396.934 1583
Radio Interferometers Track Airborne Vehicles—M. W. Miles. (*Electronic Ind.*, vol. 17, pp. 94–95, 151; October 1958.) Basic problems in interferometer systems are examined.

621.396.96 1584
Miniature *X*-Band Radar Has High Resolution—C. D. Hardin and J. Salerno. (*Electronics*, vol. 32, pp. 48–51; January 20, 1959.) The unit operates with a pulse repetition frequency of 100 kc and peak power 150 w. The IF is 400 mc with a bandwidth of 100 mc and gain 36 db in four stages. A low-range altimeter with a full-scale reading of 30 feet and calibrated at 6-inch intervals has been constructed.

621.396.96:551.594.5 1585
A Low-Power V.H.F. Radar for Auroral Research—R. S. Leonard. (PROC. IRE, vol. 47, pp. 320–322; February, 1959.)

621.396.96.083.7 1586
Radar Data Transmission.—T. E. Schilizzi—(*Proc. IRE (Australia)*, vol. 19, pp. 467–480; September, 1958.) Practical methods of achieving a remote display over wide-band and narrow-band circuits are reviewed and an experimental system using wide-band radio links is outlined. Image-converter and bright-image storage tubes for large-screen projection equipment are described. See also 2770 of 1957 (Dixon and Thomas).

621.396.962.012:681.142 1587
An Analogue Computer for Evaluating Radar Performance—Willhite and McIntyre. (See 1465.)

621.396.963 1588
Dynamic Compression for Radar Receivers—D. Levine (*Electronic Ind.*, vol. 17, pp. 102–106 and 82–84; October and November, 1958.) Various types of receiver are examined in terms of crt brightness for direct observation and for recording on film. Graphs are given to assist in the selection of the required dynamic compression curve for the system in which the receiver is to be used.

621.396.967 1589
The Rotterdam Harbour Radar System—B. H. G. Prins and J. M. G. Seppen. (*Phillips Telecommun. Rev.*, vol. 20, pp. 16–30; September, 1958.) A chain of seven radar stations working in the 3-cm band provides accurate positional information to ships with the aid of leading lines and cursor lines which are superimposed electronically on display screens.

621.396.967:621.372.413:621.317.799 1590
A Radar Echo Box with Remote Control—G. van Gelder and E. Scholten. (*Philips Telecommun. Rev.*, vol. 20, pp. 33–38; September, 1958.) A description of the construction of a high-Q resonant cavity for the 8.5- or 10-cm band and its tuning mechanism. It can be used for the measurement of the over-all performance of a radar installation and for obtaining the power spectrum of a magnetron pulse.

621.396.967.029.65 1591
An 8-mm, High-Definition Radar Set—J. M. G. Seppen and J. Verstraten. (*Philips Telecommun. Rev.*, vol. 20, pp. 5–15; September 1958.) The design of the equipment is discussed and general circuit features and photographs of the radar display are given.

621.396.967.2 1592
Development of the DEW Line—G. R. Frantz. (*Bell. Lab. Rec.*, vol. 37, pp. 2–6; January, 1959.) A general outline of the radar warning system is given.

MATERIALS AND SUBSIDIARY TECHNIQUES

535.215:546.482.21 1593
Photochemical Effects and the Effect of Oxygen on Photoconducting Cadmium Sulphide Crystals—J. Woods. (*J. Electronics Control*, vol. 5, pp. 417–426; November, 1958.) The

photochemical effects and the effects of heat treatment in oxygen on a number of differently activated crystals are described and discussed.

535.215:546.482.21 1594
Growth of Photoconductivity of Single Crystals of Cadmium Sulphide from Irradiation in an Atomic Pile—M. Martineau. (*Compt. rend. Acad. Sci. Paris*, vol. 247, pp. 639–643; August 11, 1958.)

535.37 1595
Luminescence and Luminescent Materials—D. G. Anderson. (*J. Electronics Control*, vol. 5, pp. 457–470; November, 1958.) "A general review of luminescent materials is given, with some emphasis on the more recent applications. The theoretical aspects of the absorption and emission processes are discussed briefly."

535.37:546.472.21 1596
Electron Traps in Zinc-Sulphide Phosphors—W. Hoogenstraaten. (*Philips Res. Rep.*, vol. 13, pp. 515–693; December, 1958.) An attempt is made to clarify the chemical and physical nature of electron traps in ZnS phosphors, including those based on mixed crystals of ZnS with CdS or ZnSe.

535.376 1597
Electroluminescence and Image Intensification—G. Diemer, H. A. Klasens and P. Zalm. (*Philips Tech. Rev.*, vol. 19, pp. 1–11; July 27, 1957.) The mechanism of electroluminescence and the application of the effect in solid-state image intensifiers is discussed.

535.376:539.234 1598
Electroluminescent Thin Films—W. A. Thornton. (*J. Appl. Phys.*, vol. 31, pp. 123–124; January, 1959.) Thin luminescent films of ZnS-Cu, Cl and ZnS-Cu,Mn,Cl have been prepared by a two-step evaporation/firing process similar to that described by Feldman and O'Hara (3494 of 1957) but using finished electroluminescent powder phosphors as the starting material.

537.226/.227:546.431.824–31 1599
On Growing $BaTiO_2$ Single Crystals—A. M. Cherepanov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2280–2284; October, 1957.) Triangular crystals with a hypotenuse up to 15 mm long are obtained after heating 1 $BaCl_2 \cdot 0.53$ $BaCO_3 \cdot 0.26$ TiO_2 to a temperature of 1300–1450°C. These crystals have lattice characteristics $a = 3.986$ Å, $c = 4.026$ Å, and a Curie point at 122°–123°C.

537.226:546.212–16 1600
Dielectric Properties of Ice Crystals—(*Helv. Phys. Acta*, vol. 30, pp. 553–610; December 30, 1957. In German, with English summaries.)

Part 1—Dynamic Theories of Dielectric Constants—A. Steinemann and H. Graünicher (pp. 553–580.)

Part 2—Dielectric Investigations on Ice Crystals with Occluded Impurity Atoms—A. Steinemann (pp. 581–610).

537.226:546.431.824–31 1601
Dielectric Properties of Barium Titanate at High Frequencies and Low Temperatures—H. Rabenhorst and J. Melcherčík. (*Ann. Phys.*, (*Lpz.*), vol. 1, pp. 261–263; May 20, 1958.) Dielectric constant and loss factor have been measured in the temperature range $-180°$ to $+20°$C at a frequency of 9.1 kmc.

537.226:621.319.2 1602
Contribution to the Phenomenological Theory of Electron—A. N. Cubkin. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1954–1968; September, 1957.) Five dielectrics, carnauba wax, naphthalene, steatite, nylon and magnesium titanate, were prepared under fields ranging from 5 to 25 kv per cm and observed for as long as three months. An expression is derived for the lifetime of these electrets and experimental and calculated results are tabulated.

537.226:621.319.2 1603
The Anomalous Stability of New Inorganic Polycrystalline Electrets—A. N. Gubkin and G. I. Skanavi. (*Zh. Tech. Fiz.*, vol. 27, pp. 1969–1970; September, 1957.) Experiments show that the properties of $CaTiO_3$ electrets of specific conductivity $10^{-12} - 10^{-14}$ Ω^{-1} cm^{-1} are similar when kept open-circuited or short-circuited by metallic foils. See also 3164 of 1957.

537.311.33 1604
Contribution to the Theory of Semiconductors with Excited Inpurity Zone—M. I. Klinger and Yu. I. Zozulya. (*Zh. Tekh. Viz.*, vol. 27, pp. 2285–2290; October, 1957.) The variations of conductivity, Hall effect and thermo-EMF as functions of temperature in n-type semiconductors are discussed.

537.311.33:546.23 1605
Self-Diffusion in Selenium—B. I. Boltaks and B. T. Plachenor. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2229–2231; October, 1957.) Results of an investigation of the diffusion of impurities in crystalline and amorphous Se are given. The difference between the diffusion constants for the two types increases with increasing temperature.

537.311.33:546.23:536.2 1606
The Influence of Bromine Additives on the Thermal Conductivity of Selenium—G. B. Abdullaev and A. A. Bashshaliev. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1971–1975; September, 1957.) Amorphous and crystalline Se samples with Br content varying from 0.008 to 0.5 per cent were tested at 27.5°C; their thermal conductivity coefficients were respectively 3.08×10^{-3} and 7.02×10^{-3} cal/deg. cm sec.

537.311.33:546.24:538.214 1607
Magnetic Susceptibility in Semiconductors of the Tellurium Type—Yu. A. Firsov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2212–2228; October, 1957.) A mathematical analysis of zone junctions. A method is proposed for the investigation of the zone structure based on the angular dependence of susceptibility in strong magnetic fields.

537.311.33:546.28 1608
Lattice Absorption Bands in Silicon—F. A. Johnson. (*Proc. Phys. Soc.*, vol. 73, pp. 265–272; February 1, 1959.) Detailed measurements are described of the absorption spectrum of pure vacuum-grown Si crystals, for wavelengths 2μ–30μ and at temperatures of 20, 77, 290 and 365°K. Some new absorption bands were found. The positions and temperature dependence of all the principal absorption peaks are explained in terms of multiple phonon interactions.

537.311.33:546.28 1609
The Effect of Heat Treatment on the Breakdown Characteristics of Silicon p-n Junctions—A. R. Plummer. (*J. Electronics Control*, vol. 5, pp. 405–416; November, 1958.) Soft breakdown, a more gradual breakdown than the normal avalanche characteristic, can be due to unsatisfactory bulk properties, which can be induced by heat treatment. An explanation for the effect is suggested.

537.311.33:546.281.26:537.533 1610
Electron Emission from Breakdown Regions in SiC p-n Junctions—L. Patrick and W. J. Choyke. (*Phys. Rev. Lett.*, vol. 2, pp. 48–50; January 15, 1959.) The maximum emission was found to range from 10^{-12}A to 10^{-6}A, the emission depending strongly on sample preparation.

537.311.33:546.289 1611
A Note on the Theory of Diffusion of Copper in Germanium—M. D. Sturge. (*Proc. Phys. Soc.*, vol. 73, pp. 297–306; February 1, 1959.)

537.311.33:546.289 1612
The Diffusion of Boron in Germanium—M. D. Sturge. (*Proc. Phys. Soc.*, vol. 73, pp. 320–322; February 1, 1959.)

537.311.33:546.289 1613
Electrical Properties of Germanium Doped with Zinc—S. G. Kalashnikov, E. Yu. L'vova and V. V. Ostroborodova. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1925–1930; September, 1957.) Zn has little effect on recombination velocity and appears to be suitable for doping Ge to give a low specific resistance and long electron lifetime.

537.311.33:546.289 1614
The Influence of Elements of Groups III and V on the Recombination Velocity of Electrons and Holes in Germanium—V. G. Alekseeva, S. G. Kalashnikov, L. P. Kalnach, I. V. Karpova and A. I. Morozov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1931–1939; September, 1957.) Shorter electron and hole lifetimes were obtained with Bi and Tl than with Sb and Ga. Elements possessing a small distribution coefficient such as Bi, Tl, Cu, Ni and Fe strongly accelerated the electron-hole recombination but elements such as Sb and Ga with a larger coefficient proved much less active. Co, Mn and Au seemed also to accelerate this recombination in Ge.

537.311.33:546.289 1615
Valley-Orbit Splitting of Arsenic Donor State in Germanium—G. Weinreich, W. S. Boyle, H. G. White and K. F. Rodgers. (*Phys. Rev. Lett.*, vol. 2, pp. 96–98; February 1, 1959.) Investigation of the far-infrared excitation spectrum of bound electrons in an elastically strained sample verifies that of the two states into which the donor ground state is split, the triplet is the lower one.

537.311.33:546.289 1616
Edge Breakdown of p-n Junctions in Germanium—B. M. Vul and A. P. Shotov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2189–2194; October, 1957.) Investigation shows that the permittivity of the medium influences appreciably the breakdown voltage of n^+p junctions but affects only slightly the p^+n and diffusion junctions. This can be explained by assuming a negative charge on the Ge surface which has the effect of altering the thickness of the junction near the surface.

537.311.33:546.289 1617
Ambipolar Transport of Carrier Density Fluctuations in Germanium—J. E. Hill and K. M. van Vliet. (*Physica*, vol. 24, pp. 709–720; September, 1958.) A theoretical study is made of the spectrum of generation-recombination noise at relatively high field strengths. Experimental results for near-intrinsic crystals confirm that if the ambipolar drift velocity is sufficiently large the noise spectrum is quite different from that at low field strengths.

537.311.33:546.289 1618
The Diffusion Constant, Mobility and Lifetime of Minority Carriers in Germanium Containing Parallel Arrays of Dislocations—J. B. Arthur, A. F. Gibson, J. W. Granville and E. G. S. Paige. (*Phil. Mag.*, vol. 3, pp. 940–949; September, 1958.) Measurements of the diffusion constant D show that for n-type Ge D is anisotropic; for p-type Ge D is isotropic, and the carrier lifetime anisotropic. Measurements of drift mobility of holes in n-type Ge at high

electric fields show this to be anisotropic with respect to the dislocation array, no comparable effect occurring in p-type material. A qualitative interpretation of the data is given. See also 494 of 1958 (Bell and Hogarth).

537.311.33:546.289 1619

An Interpretation of Certain Transport Properties in Germanium Containing Parallel Arrays of Edge Dislocations—A. F. Gibson and E. G. S. Paige. (*Phil. Mag.*, vol. 3, pp. 950–960; September, 1958.) Using a model similar to that considered by Read (457 of 1955), a quantitative interpretation is given of the anisotropic effects observed by Arthur *et al.* (1618 above). The diameter of the space-charge cylinder surrounding the dislocations (1.6×10^{-4} cm) and the fraction of time (about one half) that an injected hole spends within the space-charge region are deduced from the analysis.

537.311.33:546.289:537.32 1620

Thermoconductivity of Germanium—E. D. Devyatkova and I. A. Smirnov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1944–1949; September, 1957.) The thermoconductivity of eight p-type and n-type samples was examined in the temperature range 80°–300°K. Below 200°K the thermoconductivity for similar types of Ge depended on the current-carrier concentration. The p-type Ge showed a greater thermoconductivity than the n-type.

537.311.33:546.289:538.632 1621

The Temperature Dependence of the Hall Coefficient in Semiconductors with Constant Carrier Concentration—E. I. Kaplunova and K. B. Tolpygo. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2246–2251; October, 1957.) Mathematical treatment with reference to Ge. Results are shown graphically.

537.311.33:546.482.21 1622

Space-Change Limited Currents in Insulating Materials—G. T. Wright. (*Nature, (London)*, vol. 182, pp. 1296–1297; November 8, 1958.) The steady I/V characteristic of a plate of CdS about 3×10^{-3} cm thick provided with a cathode of In metal and an anode of colloidal graphite is shown. In the reverse direction the crystal was, as expected, an insulator.

537.311.33:546.561–31 1623

Diamagnetic Zeeman Effect and the Exciton Structure in Cuprous Oxide Crystals—E. F. Gross and B. P. Zakharchenya. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1940–1943; September, 1957.) See also 1499 of 1957.

537.311.33:546.682.19 1624

Preparation of Indium Arsenide—R. H. Harada and A. J. Strauss. (*J. Appl. Phys.*, vol. 30, p. 121; January, 1959.)

537.311.33:546.682.86 1625

Electrical Conduction in n-Type InSb between 20°K and 300°K—E. H. Putley. (*Proc. Phys. Soc.*, vol. 73, pp. 280–290; February 1, 1959.) Measurements are reported of the electrical conductivity and Hall coefficient for samples of InSb containing from 5×10^{13} to 10^{18} conduction electrons per cm^3. The intrinsic carrier concentration is calculated from the results obtained above 180°K. The Hall mobility results are explained as due to a combination of acoustic lattice and ionized-impurity scattering.

537.311.33:621.314.7 1626

Multiplication of Minority-Carrier Current in the Nonideal p-n Junction—V. I. Stafecv. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2195–2211; October, 1957.) The possibility of increasing minority-carrier current by means of a nonideal p-n junction is examined. Alloy transistors of p-n-p and n-p-n type with $\alpha>1$ and a region of negative resistance in the collector circuit are considered. The disruptive voltage can be adjusted from a few volts to 150–250 v and current after breakdown may reach 150–300 ma. The time of passage from one state to another is 0.1–0.2 μs. See also 1893 of 1956 (Schenkel and Statz).

538.22:538.569.4 1627

Paramagnetic Spectra of Substituted Sapphires: Part 1—Ruby—E. O. Schulz-DuBois. (*Bell Sys. Tech. J.*, vol. 38, pp. 271–290; January, 1959.) Resonance properties of Cr^{+++} ions in Al_2O_3 have been investigated theoretically and experimentally for three-level solid-state maser application. Energy levels and associated eigenvectors are presented as functions of applied magnetic field, and transition probabilities at certain orientations are discussed. Paramagnetic spectra for signal frequencies between 5 and 24 kmc are shown.

538.22:538.569.4 1628

Paramagnetic Resonance Spectrum of Cr^{+++} in Emerald—J. E. Geusic, M. Peter and E. O. Schulz-DuBois. (*Bell. Sys. Tech. J.*, vol. 38, pp. 291–296; January, 1959.) Spectra observed in the X, K and M bands gave the spectroscopic splitting factors for this material. The large value of zero-field splitting observed suggests an application as a solid-state maser for higher microwave frequencies.

538.22:538.569.4 1629

Paramagnetic Resonance in the 10000-Mc/s Band of Europium and Gadolinium subjected to a Cubic Crystalline Field—C. Ryter. (*Helv. Phys. Acta*, vol. 30, pp. 353–373; October 15, 1957. In French.)

538.22:538.569.4 1630

Theory of Paramagnetic Resonance of Europium and Gadolinium subjected to a Cubic Crystalline Field—R. Lacroix. (*Helv. Phys. Acta*, vol. 30, pp. 374–394; October 15, 1957. In French.)

538.221 1631

Some Magnetic Properties of Dilute Ferromagnetic Alloys: Part 2—B. W. Lothian, A. C. Robinson and W. Sucksmith. (*Phil. Mag.*, vol. 3, pp. 999–1012; September, 1958.) Part 1: 3667 of 1955 (Bate *et al.*).

538.221:621.318.134:538.614 1632

Faraday Effect and Birefringence in Ferrites at Microwave Frequencies—F. Mayer. (*Ann. Télécommun.*, vol. 12, pp. 279–288, 305–332, and 334–342; July–October, 1957.)

538.221:621.318.134:548.0 1633

Some Properties of Mixed Gadolinium-Erbium and Gadolinium-Yttrium—G. Villers, J. Loriers and C. Claudel. (*Compt. rend. Acad. Sci., Paris*, vol. 247, pp. 710–713; August 25, 1958.)

538.221:621.318.134:621.318.57 1634

Observations of Rotational Switching in Ferrites—W. L. Shevel, Jr. (*IBM J. Res. Developm.*, vol. 3, pp. 93–95; January, 1959.) Experimental data on switching times as a function of applied field for square-loop ferrites, suggest three mechanisms of flux reversal, each being dominant over a certain region of the curve of inverse switching time against applied field.

621.315.61:621.318.4 1635

Special-Purpose Magnet-Wire Insulation—G. Sideris. (*Electronics*, vol. 32, pp. 60–61; February 13, 1959.) A brief review of wires available in U.S.

MATHEMATICS

512:621.316.5 1636

Ternary Switching Algebra—E. Mühldorf. (*Arch. elekt. Übertragung*, vol. 12, pp. 138–148; March, 1958.) A switching algebra is developed for use in systems with a ternary code.

517.949.8:681.142 1637

The Z Transformation—H. A. Helm. (*Bell Sys. Tech. J.*, vol. 38, pp. 177–196; January, 1959.) "The Stieltjes integral is used to develop a rigorous derivation of the z transform. Sufficient properties of the transformation are included to form a reasonably complete basis for the operational solution of constant-coefficient, linear, finite-difference equations."

519.251.7:53.088 1638

Analysis of Errors in the Determination of the Mean Value of a Random Quantity and of its Mean Square Error due to the Finite Time of Observation—A. E. Kharybin. (*Aytomalika i Telemekhanika*, vol. 18, pp. 304–314; April, 1957.) Formulas are derived and nomograms are plotted by means of which it is possible *a*) to estimate whether the interval for the observation of a random quantity is sufficient, and *b*) to find the assumed m^{2}an-square errors in the determination of the mean value and its dispersion for a typical case.

519.2 1639

The Advanced Theory of Statistics. Vol. 1: Distribution Theory. [Book Review]—M. G. Kendall and A. Stuart. Publishers: Griffin, London, Eng., 1958, 433 pp., 84s. (*Nature (London)*, vol. 182, p. 1470; November 29, 1958.)

MEASUREMENTS AND TEST GEAR

621.3.018.41(083.74) 1640

Standard-Frequency Transmissions—(*Electronic Radio Eng.*, vol. 36, pp. 117–118; March, 1959.) Details are given of a new method of adjusting the MSF standard-frequency transmission with reference to the second of Ephemeris Time (ET), to be operated from March, 1959. The MSF frequency corrections published monthly in *Electronic Radio Eng.* will be given to ±1 part in 10^{10}, and the form of presentation will be changed.

621.3.018.41(083.74):538.569.4 1641

Theory of the Cavity Microwave Spectrometer and Molecular Frequency Standard—Y. Beers. (*Rev. Sci. Instr.*, vol. 30, pp. 9–16; January, 1959.) The theory predicts that a considerable improvement in signal/noise ratio and sensitivity can be obtained in the cavity spectrometer. A fractional stability of about 4×10^{-12} can be achieved in a frequency standard using the 3.3 ammonia line.

621.317.3:621.372.412 1642

Quartz Crystals Require Testing for Spurious Response—A. N. Silverstein. (*Electronic Ind.*, vol. 17, pp. 85–88; October, 1958.) The test equipment described is a modified form of the low-frequency spectrum analyzer reported by McDuffie (202 of 1956). It is used for detecting interfering spurious responses in quartz crystals operating in the frequency range 20–60 mc.

621.317.361+621.317.373 1643

A Pulse-Beat Method for Accurate Frequency and Phase Measurements and Phase-Locked Frequency Changing—G. Becker. (*Frequenz*, vol. 12, pp. 82–90; March, 1958.) A method is described for accurate short-term comparison of two standard frequencies, particularly if their relations are rational, even if they differ considerably in magnitude. A differentiation method for accurate determination of

phase coincidence, and the principle of phase-locking a frequency changer are outlined.

621.317.42:538.569.4 1644
Measurement of Magnetic Fields by Nuclear Resonance—G. C. Lowe. (*Electronic Eng.*, vol. 31, pp. 138–140; March, 1959.) A simple feedback circuit is described for the accurate measurement of magnetic fields over a wide range with little readjustment of circuit elements.

621.317.6:621.3.001.4 1645
Sorting Components by Measuring Waveforms—B. Agusta. (*Electronics*, vol. 32, pp. 56–59; February 13, 1959.) Waveform characteristics of circuit components are obtained by sampling at discrete time intervals. A pulse whose amplitude is proportional to that of the waveform at the sampling time is produced and a digital output reading is obtained.

621.317.7:621.314.7 1646
Measurement of Junction-Transistor Equivalent-Circuit Parameters—J. J. Sparkes. (*A.T.E. J.*, vol. 14, pp. 176–187; July, 1958.)

621.317.7:621.314.7 1647
A Transistor D.C.-A.C. Beta Tester—T. P. Sylvan. (*Electronic Ind.*, vol. 17, pp. 90–92; October, 1958.) Details are given of a tester for measuring both the dc and ac common-emitter current gain and the collector-to-emitter leakage current.

621.317.733:[621.314.63+621.314.7 1648
Capacitance Bridges for Semiconductor Measurements—N. F. Blackburne. (*A.T.E. J.*, vol. 14, pp. 166–175; July, 1958.) Two bridges are described. The first is an admittance bridge for measurement of the effective parallel resistance and capacitance of *p-n* junctions under forward, reverse and zero bias in the frequency range 1 kc–1 mc. The second bridge measures collector capacitance and extrinsic base resistance of junction transistors at frequencies up to 10 mc. Measurements can be made at elevated temperatures.

621.317.734 1649
On the Accuracy of the Ohmmeter—R. Braae. (*Engineer* (*London*), vol. 206, pp. 563–565; October 10, 1958.) The classical theory of errors is used to analyze the capabilities and limitations of measuring equipment, particularly of ohmmeters.

621.317.75 1650
The Recording and Collocation of Waveforms: Part 1—R. J. D. Reeves. (*Electronic Eng.*, vol. 31, pp. 130–137; March, 1959.) The basic principles and history of stroboscopic oscillographs are given. Modern methods of strobe pulse generation, synchronization and time delay are discussed.

621.317.77 1651
Measurement of Phase and Amplitude at Low Frequencies—R. J. A. Paul and M. H. McFadden. (*Electronic Eng.*, vol. 31, pp. 142–149; March, 1959.) Description of a lf oscillator and phasemeter for testing feedback control systems. The range extends from below 0.01 cs to at least 10 kc.

621.317.794:537.324 1652
Thermocouples and Bolometers for Radiation Measurements in the Infrared Spectral Region—G. Grave and W. Heimann. (*Elektronik*, vol. 7, pp. 65–69; March, 1958.) The construction of sensitive radiation measuring equipment is described with brief details of apparatus for medical applications.

621.317.794:537.324 1653
Noise in Radiation Thermocouples—V. Schley and F. Hoffmann. (*Optik*, vol. 15, pp. 358–371; June, 1958.) Measurements indicate that solder joints to the couple may be a source of thermal noise.

OTHER APPLICATIONS OF RADIO AND ELECTRONICS

535.376.07 1654
Solid-State Panels for Display or Storage—R. K. Jurgen. (*Electronics*, vol. 32, pp. 46–47; January 30, 1959.) The use of photorectifier matrices with packing densities of 256 per inch^2 for character generation and storage is described.

621–52:621.395.625.3 1655
Magnetic Drum Provides Analogue Time Delay—H. L. Daniels and D. K. Sampson. (*Electronics*, vol. 32, pp. 44–47; February 6, 1959.) The use of a magnetic drum to provide delays of between 5 and 20 s is described. A recording range of ±50 v and an accuracy within 0.1 per cent for frequencies between 0 and 1 cs are achieved.

621–52:681.142 1656
Digital System Positions Shafts over Phone Line—R. B. Palmiter. (*Electronics*, vol. 32, pp. 62–66; February 13, 1959.) Description of a carrier system by which data describing the position of three master shafts as well as all necessary synchronizing and auxiliary information are transmitted over a telephone line for controlling slave shaft positions.

621.384.6:621.319.339 1657
An Accelerator with an 800-kV Cascade Generator—K. Simonyi. (*Acta Tech. Acad. Sci. Hung.*, vol. 19, pp. 353–362; 1958. In German.) Description of an installation of the Central Physical Research Institute, Budapest, with details of the rectifier-valve heating and ion focusing arrangements.

621.396.969:533.6.011.7 1658
Radio Observations of Hypersonic Shock Waves—J. S. Hey, J. T. Pinson and P. G. Smith. (*Nature* (*London*), vol. 182, pp. 1220–1221; November 1, 1958.) Application of the Doppler technique described earlier (3625 of 1957).

621.398:621.376.5 1659
A Static Transmitting Device for Pulse-Frequency Telemetry Systems—A. M. Pshenichnikov. (*Avtomatika i Telemekhanika*, vol. 18, pp. 444–448; May, 1957.) Description of a magnetic-modulator/multivibrator circuit with compensating feedback network. The frequency of the multivibrator output is a linear function of the measured quantity. Advantages over existing types of transmitting device are noted.

PROPAGATION OF WAVES

621.396.11 1660
On the Spectrum of a Passive Scalar Mixed by Turbulence—A. D. Wheelon. (*J. Geophys. Res.*, vol. 63, pp. 849–850; December, 1958.) A discussion of 1527 and 1533 of 1958 (Bolgiano). Previous analysis (2881 of 1957) is extended to show that removal of spectral content by convective transfer is more important than diffusion damping throughout the inertial range, whatever the spectrum may be. See also 1661 below and *ibid.*, pp. 854–855.

621.396.11 1661
On the Role of Convective Transfer in Turbulent Mixing—R. Bolgiano, Jr. (*J. Geophys. Res.*, vol. 63, pp. 851–853; December, 1958.) The extended theory given by Wheelon (1660 above) is not necessarily valid, since additional mechanisms of transfer (rather than dissipation) are introduced. The differences between the two theories are due to conceptually distinct methods of treating the convective transfer process.

621.396.11 1662
Propagation of Electromagnetic Pulses Around the Earth—B. R. Levy and J. B. Keller. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 56–61; January, 1958. Abstract, PROC. IRE, vol. 46, p. 799; April, 1958.)

621.396.11 1663
Scattering of Electromagnetic Waves in Beyond-the-Horizon Radio Transmission—D. I. Paul. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 61–65; January, 1958. Abstract, PROC. IRE, vol. 46, p. 799; April, 1958.)

621.396.11 1664
Downcoming Radio Waves—J. R. Wait. (*Electronic Radio Eng.*, vol. 36, pp. 106–107; March, 1959.) A method of measuring the angle of arrival, azimuth and polarization of a downcoming radio wave using a crossed-loop direction finder with a four-element Adcock antenna.

621.396.11:523.53 1665
Electromagnetic Scattering by Low-Density Meteor Trails—H. Brysk. (*J. Geophys. Res.*, vol. 63, pp. 693–716; December, 1958.) A uniform underdense line of electrons is considered and the model is then extended to include diffusion and to take account of the fast initial movement of the particles before they are slowed to thermal velocities. The effect of antenna gain is discussed. Various limiting cases are examined and expressions are given for specular and nonspecular scattering.

621.396.11:551.510.52 1666
Wavelength Dependence in Transhorizon Propagation—R. Bolgiano, Jr. (PROC. IRE, vol. 47, pp. 331–332; February, 1959.) An experiment to determine the wavelength dependence of the scattering coefficient in tropospheric scatter propagation is described. Scaled antennas at 417 mc and 2290 mc were used, and a wide range found for the wavelength dependence. The variation is considered to be statistically significant and to correspond to a variation in the meteorological processes responsible for the scattering.

621.396.11:551.510.535 1667
On the Reciprocity of H.F. Ionospheric Transmission—M. Balser, W. B. Smith and E. Warren. (*J. Geophys. Res.*, vol. 63, pp. 859–861; December, 1958.) Describes preliminary simultaneous two-way tests with pulses over a 1685-km path in Canada, using the same antenna at each terminal for both receiving and transmitting. Sample records show nonreciprocal effects in the fading, even though antennas insensitive to Faraday rotation were used.

621.396.11:551.510.535 1668
Polarization Fading over an Oblique-Incidence Path—D. A. Hedlund and L. C. Edwards. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 21–25; January, 1958. Abstract, PROC. IRE, vol. 46, p. 799; April, 1958.)

621.396.11:551.510.535:537.56 1669
Equivalence Theorems of Wave Absorption in Plasma—K. Rawer and K. Suchy. (*Ann. Phys., Lpz.*, vol. 1, pp. 255–260; May 20, 1958.) Using wave and ray theory and neglecting the earth's magnetic field it is shown that Martyn's theorem of ionospheric absorption is valid only if attenuation is mainly due to collisions and is proportional to the number of collisions.

621.396.11:551.594.5 1670
Radio Echoes from Auroral Ionization Detected at Relatively Low Geomagnetic Lati-

tudes—R. L. Leadabrand and A. M. Peterson. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 65–79; January, 1958. Abstract, PROC. IRE, vol. 46, p. 799; April, 1958.)

621.396.11:551.594.5 1671
The Geometry of Auroral Communications—R. L. Leadabrand and I. Yabroff. (IRE TRANS. ON ANTENNAS AND PROPAGATION, vol. AP-6, pp. 80–87; January, 1958. Abstract, PROC. IRE, vol. 46, pp. 799–800; April, 1958.)

621.396.11.029.45:621.396.67:621.315.1 1672
Power-Line Aerial—R. M. Golden, R. V. Langmuir, R. S. Macmillan and W. V. T. Rusch. (*Electronic Radio Eng.*, vol. 36, pp. 116; March, 1959.) A note on propagation experiments carried out in California using an 8-mile section of medium-voltage single-phase power transmission line as a radiator at 8.4 kc. Parallel-resonant circuits tuned to the operating frequency were used to isolate the line, and the power supplied to the aerial terminals was 10 kw. Measurements of extremely strong ionospheric reflections have been made at near-vertical incidence, and satisfactory signals have been detected 250 km away.

621.396.11.029.64 1673
Radio Attenuation at 11 kMc and Some Implications affecting Relay System Engineering—S. D. Hathaway and H. W. Evans. (*Bell Sys. Tech. J.*, vol. 38, pp. 73–97; January, 1959.) Measurements have been made of attenuation and rainfall over paths of length 27 and 12 miles. The results are compared with theoretical expectations of attenuation, and the effect of attenuation on usable path length is discussed.

RECEPTION

621.376.23:621.396.822 1674
The Response of Nonlinear Devices to Band-Limited High-Frequency Signals and Noise—N. W. W. Smith. (*J. Electronics Control*, vol. 5, pp. 385–401; November, 1958.) "The envelope detection model is used to describe the response of nonlinear devices *e.g.* detectors and mixers) to band-limited high-frequency signals. Results obtained for discrete sinusoidal signals are shown to be applicable to the continuous spectra of high-frequency noise without recourse to probability theory."

621.396.3 1675
A Modern Frequency-Shift Telegraph Receiver—E. J. Allen. (*Electronic Eng.*, vol. 31, pp. 161–164; March, 1959.) In this system the "mark" and "space" signals are separated. Since diversity reception is employed, two mark and two "space" signals are available, each pair of which are combined in a ratio squarer. The resultants are converted to double-current signals and added. The system will function with only one of the four signals present.

621.396.62+621.397.62]:658.5 1676
Some Uses of Statistical Methods in the Manufacture of Radio and Television Receivers—A. I. Godfrey. (*J. Brit. IRE*, vol. 19, pp. 15–28; January, 1959.)

621.396.621 1677
Receivers with Zero Intermediate Frequency—J. C. Greene and J. F. Lyons. (PROC. IRE, vol. 47, pp. 335–336; February, 1959.) Measurements made on a frequency-sweep receiver covering the range 500–950 mc at a sweep rate of 10 cps and using a low-pass video amplifier in place of a normal IF stage, indicated an average noise figure of 8 db.

621.396.662 1678
Some Aspects of Permeability Tuning—W. D. Meewezen. (*J. Brit. IRE*, vol. 19, pp. 47–60; January, 1959.) Reprint, See 3622 of 1958.

621.396.662:534.76 1679
F.M. Tuner Adapter for Multiplexed Stereo—L. Feldman. (*Electronics*, vol. 32, pp. 52–54; February 6, 1959.) Description of a 4-valve converter unit for the reception of a multiplex-type two-channel stereophonic transmission.

621.396.821:551.495.6 1680
Study of the Atmospheric Radio Noise at 27 and 100 kc/s at Delhi—Sachdev. (See 1580.)

621.396.822 1681
The Spectrum of Limited Gaussian Noise—F. L. H. M. Stumpers. (*Philips Res. Rep.*, vol. 13, pp. 509–514; December, 1958.) "The energy spectrum of the output of a nonlinear device with an input of Gaussian noise can be expressed directly in terms of the Laplace transform of its characteristic and of convolutions of the input bandpass form. The expression is derived and the result applied to several forms of limiter characteristic. The same method can be applied if a carrier signal is also present."

621.396.822 1682
Some Aspects of Noise in Communications and Servo Systems—R. M. Huey. (*Proc. IRE (Australia)*, vol. 19, pp. 486–493; September, 1958.) Methods of system design involving studies of the system response to random signals, as opposed to sinusoidal signals, are discussed.

STATIONS AND COMMUNICATION SYSTEMS

621.391 1683
On the Mathematical Theory of Error-Correcting Codes—H. S. Shapiro and D. L. Slotnick. (*IBM J. Res. Developm.*, vol. 3, pp. 25–34; January, 1959.)

621.396.3:621.376 1684
An Experimental Modulation-Demodulation Scheme for High-Speed Data Transmission—E. Hopner. (*IBM J. Res. Developm.*, vol. 3, pp. 74–84; January, 1959.) A description is given of a low-cost system which was designed to determine speed and reliability limitations on transmitting binary data over private telephone lines.

621.396.324 1685
An Electronic Coder and Decoder for Teleprinter Signals—J. Das. (*Electronic Eng.*, vol. 31, pp. 156–160; March, 1959.)

621.396.41:621.396.62 1686
The Development of Radio Telegraphy Systems on Short Waves and its Influence on Receiver Techniques—R. Tastenoy. (*Rev. HF Brussels*, vol. 4, pp. 11–23; 1958.) A review of the principal multiplex systems and of the problems of selectivity and stability in receivers associated with these systems. Diversity reception is briefly discussed.

621.396.5 1687
Radio Link Installations for the Transmission of Telephony and Television in the 4-kMc/s and 2-kMc/s Bands—K. Christ, O. Laaff and K. Schmid. (*Elektrotech. Z., Edn A.*, vol. 79, pp. 687–693; October 1, 1958.) The equipment of two FM systems is described. The 4-kmc system has a capacity of 600 telephony channels or one 625-line television channel, and the 2-kmc installation has 120 carrier-frequency channels; both conform to CCITT and CCIR recommendations.

621.396.5.029.62 1688
Radio Transmission into Buildings at 35 and 150 Mc/s—L. P. Rice. (*Bell. Sys. Tech. J.*, vol. 38, pp. 197–210; January, 1959.) The em field on the ground floor of a building was found to be 20–25 db less than the median field in city streets at the same distance from the transmitter. It is shown that the effective coverage range in buildings is greater for the higher frequency.

621.396.65:621.396.933 1689
Radio Links for the Control of Aeronautical Air-Ground-Air Equipment—W. S. McGuire. (*Proc. IRE (Australia)*, vol. 19, pp. 541–550; October, 1958.) A multichannel FM system between Melbourne and outlying stations for the control of aircraft communication equipment is described. Frequency bands used are 160 mc and 450 mc; equipment is duplicated, and automatic change-over switching and test facilities are provided.

621.396.712 1690
Common-Channel Common-Programme Operation of Medium-Wave Broadcasting Stations—S. F. Brownless. (*Proc. IRE, Australia*, vol. 19, pp. 529–541; October, 1958.) Two experimental systems are described, one using a low-power booster transmitter, the other using two manually synchronized crystal-controlled high-power transmitters. Conclusions are drawn from the test results reported. 30 references.

621.396.721:621.395.623.8 1691
Sound Distribution at the Brussels Exhibition—A. V. J. Martin. (*Audio Eng.*, vol. 43, pp. 26–28, 80; February, 1959.) Five 250-w FM transmitters were used to supply about 450 sound sources, each consisting of one receiver feeding four loudspeakers. The receivers distributed over the exhibition grounds were in continuous operation for the six months' duration of the World Fair 1958. Details of circuitry and special installations are given.

621.396.74+621.397.7](434.7) 1692
The Network of Broadcast and Television Transmitters in Württemberg—H. Rupp. (*Electrotech. Z., Edn A.*, vol. 79, pp. 670–673; October 1, 1958.)

SUBSIDIARY APPARATUS

621–526:621.314.7–555.621 1693
A Simple Temperature-Control System for Transistors—H. Kemhadjian. (*Mullard Tech. Commun.*, vol. 4, pp. 186–190; December, 1958.) A description of a closed-loop servomechanism in which a power transistor, which supplies the current for a heating coil, is controlled by an error signal produced by a temperature-sensing AF transistor.

621–526:621.396.6 1694
Loop controls Scatter Power to Offset Fading—L. P. Yeh. (*Electronics*, vol. 32, pp. 60–62; January 30, 1959.) A closed-loop servo systems is described whereby the transmitted power of an UHF tropospheric scatter link is reduced under conditions of good reception and increased under fading conditions. A statistical analysis of the system is given.

621.3.087.6 1695
Converting Recorders to Rectilinear Outputs—N. D. Diamantides. (*Electronic Ind.*, vol. 17, pp. 82–84; October, 1958.) A computer circuit generating variable transport time delays is described for transforming pen recordings from arcs to straight lines. See also 1914 of 1957 (Massa and Massa).

621.311.6:621.317.7.029.6 1696
Stabilized Variable-Frequency A.C. Instrument Calibration Source—C. A. Master and W. L. Mandrell. (*Rev. Sci. Instr.*, vol. 30, pp. 38–40; January, 1959.) A network is described which renders a 20 cps–20 kc amplifier insensitive to variations of signal input, power supply and load.

621.311.62:621.316.722.1 1697
High-Stability Mains-Operated Valve Heater Supply—C. T. Murray and R. E. Aitchison. (*Proc. IRE, Australia*, vol. 19, pp. 494–495; September, 1958.) Details are given of a circuit using a high-gain tuned amplifier with feedback controlled by a thermistor bridge.

621.314.57:621.314.7 1698
A Four-Transistor D.C. Converter Circuit for Use with Relatively High-Voltage Supplies—W. L. Stephenson. (*Mullard Tech. Commun.*, vol. 4, pp. 191–192; December, 1958.) An experimental bridge circuit is described with a power output of 40 w and conversion efficiency of 90 per cent.

TELEVISION AND PHOTOTELEGRAPHY

621.397.5 1699
Television Techniques—E. Schwartz. (*Elektrotech. Z., Edn A*, vol. 79, pp. 743–746; October 1, 1958.) Review of recent developments. 69 references.

621.397.5:535.623 1700
A Simple and Compatible System for Colour Television—L. Chrétien and R. Aschen. (*TSF et TV*, vol. 33, pp. 323–324; October, 1957.) The system outlined is based on transmitting the luminance signal in a bandwidth of 5.5 mc and the chrominance signals on two subcarriers of different frequency, all within the 14-mc channel normally allotted for 819-line monochrome transmissions.

621.397.5:535.623:535.417 1701
Applications of the Interference of Light in Thin Films—P. M. van Alphen. (*Philips Tech. Rev.*, vol. 19, pp. 59–67; August 24, 1957.) The theory of optical interference and its application to dichroic mirrors for color television is briefly discussed. The construction and production of the mirrors is described.

621.397.5:621.395.625.3 1702
Eight Papers on Video Tape and Recording—(*J. Soc. Mot. Pic. Telev. Eng.*, vol. 67, pp. 721–745; November, 1958.) Problems in recording and editing video signals in the Ampex system are described and discussed. The mechanical design of the tape transport system and head is not described. The electronic system for recording and playback and the processing of the recovered signal to restore the synchronization and gating pulses is described together with the use of magnetic powders to enable splices to be located accurately. The problem of the development of high-quality tape for use with rotating heads and the importance of head alignment are discussed.

621.397.611.2:535.215 1703
Semiconducting Materials in Vidicon-Type Television Pickup Tubes—V. A. Babits. (*J. Telev. Soc.*, vol. 8, pp. 498–502; October–December, 1958.) A summary of the target materials used in the vidicon-type tube, and the physical principles underlying their performance. Possible increases in sensitivity and temperature range are suggested as a result of proper choice of material for the various layers.

621.397.621.2 1704
The Current Characteristic of TV Picture Tubes—W. F. Niklas. (*J. Telev. Soc.*, vol. 8, pp. 512–515; October–December, 1958.) The value of the exponent in the cathode current characteristic of cathode ray tubes increases from 2.5 to 3.5 with increasing current values for space-charge-limited emission.

621.397.621.2:535.623 1705
The Faraday Cell in Colour Television—R. W. Wells. (*J. Telev. Soc.*, vol. 8, pp. 503–506; October–December, 1958.) A summary of the advantages and limitations of a projection cathode ray tube with a Faraday cell and a cellophane filter.

621.397.7 1706
Isle of Wight I.T.A. Station—(*Brit. Commun. Electronics*, vol. 5, pp. 850–851; November, 1958.) An outline is given of the transmitting equipment at Chillerton Down and the microwave radio-relay system linking London and Southampton. For a similar account see *Engineer* (*London*), vol. 206, pp. 340–341; August 29, 1958.

621.397.7(4) 1707
European Television Stations—(*Wireless World*, vol. 65, pp. 109–116; March, 1959.) A comprehensive survey of European networks including summaries of services available in each country and reproductions of test cards. World television standards and European channel allocations in bands I and III are tabulated. Transmitters, links, and conversion centers for Eurovision links are indicated on a map.

TUBES AND THERMIONICS

621.314.63:546.289 1708
Blocking Junction Process in Planar Germanium Diodes Type DG-Ts—Yu. K. Barsukov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2252–2261; October, 1957.) An investigation of the first stage of the blocking process, corrsesponding to limitation of the reverse current through the diode by the resistance of the external circuit. The results for five diodes are tabulated and presented graphically.

621.314.63.002 1709
The Manufacture of Germanium Diodes—C. F. Hühn. (*Telefunken Ztg*, vol. 31, pp. 11–20; April, 1958. English summary, p. 66.) A description of the complete manufacturing process.

621.314.632 1710
High-Frequency Gallium Arsenide Point-Contact Rectifiers—W. M. Sharpless. (*Bell Sys. Tech. J.*, vol. 38, pp. 259–269; January, 1959.) Recent work is described using single crystals as frequency converters at frequencies as high as 60 kmc and as switching diodes for switching times of the order of 10^{-10}s. Satisfactory operation is obtained over a considerable range of temperature.

621.314.632:621.316.722.1 1711
Applications for Zener Diodes—G. Porter. (*Electronic Ind.*, vol. 17, pp. 108, 110; October, 1958.) Tables are given of the manufacturers of various types of Zener diode and of its applications.

621.314.7 1712
New Transistor Works at Cryogenic Temperatures—S. Weber. (*Electronics*, vol. 32, pp. 34–35; January 23, 1959.) A "grain-boundary" transistor capable of operating at temperatures as low as 2°K is described. Its operation is based on the characteristics of the boundary formed between two crystal lattice structures of different grain orientation.

621.314.7 1713
Some Criteria for the Thermal Stability of Transistors—F. Weitzsch. (*Frequenz*, vol. 12, pp. 65–71; March, 1958.) The conditions giving rise to thermal instability are analyzed and formulas are derived to determine whether a given circuit requires stabilization.

621.314.7 1714
An Analysis of Base Resistance for Alloy-Junction Transistors—A. J. Wahl. (IRE Trans. on Electronic Devices, vol. ED-5, pp. 131–139; July, 1958. Abstract, Proc. IRE, vol. 46, p. 1889; November, 1958.)

621.314.7 1715
Physical Mechanisms Leading to Deterioration of Transistor Life—G. C. Messenger. (IRE Trans. on Electronic Devices, vol. ED-5, pp. 147–151; July, 1958. Abstract, Proc. IRE, vol. 46, p. 1890; November, 1958.)

621.314.7:621.317.7 1716
Measurement of Junction-Transistor Equivalent-Circuit Parameters—J. J. Sparkes. (*A.T.E. J.*, vol. 14, pp. 176–187; July, 1958.)

621.314.7:621.317.7 1717
A Transistor D.C.-A.C. Beta Tester—Sylvan. (See 1647.)

621.314.7.012.8 1718
Transistor Equivalent Circuit—D. A. Green. (*Electronic Radio Eng.*, vol. 36, pp. 108–114; March, 1959.) A circuit is derived which is valid at all frequencies at which alloyed-junction transistors give useful gain. The circuit may be used to calculate the performance of hf amplifiers.

621.314.7.012.8 1719
The Junction Transistor as a Network Element at Low Frequencies: Part 1—Characteristics and *h* Parameters—J. P. Beijersbergen, M. Beun and J. te Winkel. (*Philips Tech. Rev.*, vol. 19, pp. 15–27; July 7, 1957.)

621.314.7.012.8:530.17 1720
The Thermal Equivalent Circuit of a Transistor—P. R. Strickland. (*IBM J. Res. Developm.*, vol. 3, pp. 35–45; January, 1959.) It is shown that an exact electrical analogue can be given for the thermal system between the collector junction and the constant-temperature environment of a transistor. An experimental method is given for obtaining the parameters of the equivalent circuit, and its application in circuit design is discussed.

621.383:546.289:535.61–1 1721
The Frequency Characteristic of a Germanium Infrared Diode Modulator—Yu. I. Ukhanov. (*Zh. Tekh. Fiz.*, vol. 27, pp. 1950–1953; September, 1957.) Infrared rays passing through a Ge diode modulator were received on a PbS photocell. The modulation coefficient was found to be constant in the frequency range 20 cps–20 kc.

621.383.27 1722
Stroboscopic Operation of Photomultiplier Tubes—C. F. Hendee and W. B. Brown. (*Philips Tech. Rev.*, vol. 19, pp. 50–58; August 24, 1957.) A technique is described for analyzing a periodically repeated low-intensity flash which is synchronized with a phase-delayed pulse to a photomultiplier tube. The tube can be triggered by a pulse as short as 10^{-7} sec to act as a light shutter, and the tube gain is much higher than under dc operation. Circuit details and experimental results are given.

621.383.5 1723
Grain-Boundary Photovoltaic Cell—R. K. Mueller and R. L. Jacobson. (*J. Appl. Phys.*, vol. 30, pp. 121–122; January, 1959.) A photocell is described which is sensitive to light-spot movement in two dimensions. It comprises a rectangular rod of *n*-type Ge containing a grain boundary perpendicular to its main axis. Ohmic contacts are applied at the ends of the sample and In contacts are alloyed on opposite sides covering the grain boundary.

621.385:621.374.32 1724
The Trochotron—N. P. R. Sherry. (*Brit. Commun. Electronics*, vol. 5, pp. 842–843; November, 1958.) A description of the mode of operation of a hot-cathode high-vacuum valve with a pulse counting rate in the region

of 10^6 per second. See also 3079 of 1954 (Björkman and Lindberg).

621.385.029.6 1725
On the Application of Harmonic Vibrations of Electrons for the Generation of Ultra High Frequencies—P. A. Borodovskiĭ. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2353–2355; October, 1957.) A brief description of results obtained with an experimental valve in which variations of the accelerating voltage from 150 to 1000 v produce frequency changes from 310 to 600 mc. See 3398 of 1954 (Alfvén and Romell).

621.385.029.6 1726
Effect of Electron Lenses on Beam Noise—R. C. Knechtli. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 84–88; April, 1958. Abstract, PROC. IRE, vol. 46, p. 1440; July, 1958.)

621.385.029.6 1727
New Mechanism of Noise Reduction in Electron Beams—M. R. Currie and D. C. Forster. (*J. Appl. Phys.*, vol. 30, pp. 94–103; January, 1959.) Experiments have demonstrated that the basic noise quantities of an electron beam can be transformed and optimized by varying the field configuration and flow characteristics in the multivelocity region near the cathode. A detailed investigation of the conditions for minimum beam noisiness is presented.

621.385.029.6 1728
Reduction of Electron-Beam Noisiness by means of a Low-Potential Drift Region—A. W. Shaw, A. E. Siegman, and D. A. Watkins. (PROC. IRE, vol. 47, pp. 334–335; February, 1959.)

621.385.029.6 1729
Ballistic Analysis of a Two-Cavity Finite-Beam Klystron—S. E. Webber. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 98–108; April, 1958. Abstract, PROC. IRE, vol. 46, p. 1440; July, 1958.)

621.385.029.6 1730
Principle of Operation and Working Data for the Power Reflex Klystron TK7—F. Möhring. (*Tech. Mitt. PTT*, vol. 36, pp. 145–149; April 1, 1958.) The klystron has a maximum hf output >5 w for a 35-mc bandwidth in the 4-kmc range.

621.385.029.6 1731
Propagation in a Crossed-Field Periodic Structure—A. Kiel, M. Scotto and P. Parzen. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 76–84; April, 1958. Abstract, PROC. IRE, vol. 46, p. 1440; July, 1958.)

621.385.029.6 1732
Characteristics of Travelling-Wave Tubes with Periodic Circuits—R. W. Gould. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 186–195; July, 1958. Abstract, PROC. IRE, vol. 46, p. 1890; November, 1958.)

621.385.029.6 1733
A Hybrid-Type Travelling-Wave Tube for High-Power Pulsed Amplification—E. J. Nalos. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 161–166; July, 1958. Abstract, PROC. IRE, vol. 46, p. 1890; November, 1938.)

621.385.029.6 1734
Conditions for Minimum Noise Generation in Backward-Wave Amplifiers—M. R. Currie and D. C. Forster. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 88–98; April, 1958. Abstract, PROC. IRE, vol. 46, p. 1444; July, 1958.)

621.385.029.6:537.533 1735
Space-Charge-Wave Excitation in Solid-Cylindrical Brillouin Beams—W. W. Rigrod and J. R. Pierce. (*Bell Sys. Tech. J.*, vol. 38, pp. 99–118; January, 1959.) The voltage and current modulation of ideal cylindrical electron beams in Brillouin flow and in beams of zero magnetic field are studied by means of Laplace transforms. The problems of field modulation by an annular gap in a drift tube and noise excitation of a beam are discussed.

621.385.029.6:537.533 1736
Space-Charge Wave Harmonics and Noise Propagation in Rotating Electron Beams—W. W. Rigrod. (*Bell Sys. Tech. J.*, vol. 38, pp. 119–139; January, 1959.) The higher-order space-charge waves on solid-cylindrical electron beams are considered. The properties of such waves are derived from slow-wave small-signal analysis.

621.385.029.6:621.316.726.078 1737
Nonvacuum Devices control Klystrons—M. C. Harp. (*Electronics*, vol. 32, pp. 68–70; February 13, 1959.) Close frequency control of transmitter and receiver local-oscillator klystrons in a 6-kc microwave link is achieved by the use of magnetic amplifiers and transistors.

621.385.029.6|621.372.2+621.372.8 1738
Electron Waves in Periodic Structures—L. A. Vaĭnshteĭn. (*Zh. Tekh. Fiz.*, vol. 27, pp. 2340–2352; October, 1957.) Relations derived earlier (338 of 1957) for retarding systems are generalized, and an expression is obtained for calculating the linear properties of travelling-wave and backward-wave valves.

621.385.029.6:621.376.3 1739
Linearization of the Frequency-Modulation Characteristic of a Reflex Klystron—E. Schuon and H. J. Butterweck. (*Arch. elekt. Übertragung*, vol. 12, pp. 99–108; March, 1958.) The characteristic can be straightened and the frequency swing increased by applying a coupled-resonator load with band-filter characteristics.

621.385.029.64/.65 1740
Two Backward-Wave Oscillator Tubes for the 29,000 to 74,000 Megacycle Frequency Range—D. J. Blattner and F. Sterzer. (*RCA Rev.*, vol. 19, pp. 584–597; December, 1958.) The characteristics and performance of two experimental backward-wave oscillator valves are described. Their wide frequency range and milliwatt-level power output make them suitable for signal-generator and local-oscillator applications.

621.385.029.64 1741
The Reflex Klystron as a Negative-Resistance-Type Amplifier—C. F. Quate, R. Kompfner, and D. A. Chisholm. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 173–179; July, 1958. Abstract, PROC. IRE, vol. 46, p. 1890; November, 1958.)

621.385.029.64 1742
A 20- to 40-kMc/s Backward-Wave Oscillator—R. W. Grew, D. A. Dunn, S. W. McLaughlin and R. P. Lagerstrom. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 152–156; July, 1958. Abstract, PROC. IRE, vol. 46, p. 1890; November, 1958.)

621.385.029.65/.66 1743
Dielectric Slow-Wave Structures for the Generation of Power at Millimetre and Submillimetre Wavelengths—R. H. Patnell, P. D. Coleman, and R. C. Becker. (IRE TRANS. ON ELECTRON DEVICES, vol. ED-5, pp. 167–173; July, 1958. Abstract, PROC. IRE, vol. 46, p. 1890; November, 1958.)

621.385.852 1744
Cathode-Ray Storage Tubes for Direct Viewing—A. S. Kramer. (*Electronics*, vol. 32, pp. 40–41; January 23, 1959.) Physical and electrical characteristics, performance data, and applications of 17 types of tube are tabulated.

621.385.832 1745
Survey of Half-Tone Image Storage Tubes—H. G. Lubszynski. (*Nachrichtentech. Z.*, vol. 11, pp. 115–124; March, 1958.) See 3362 of 1957.

621.385.832 1746
Characteristics and Applications of the Iatron Storage Tube—D. W. Davis. (*Commun. and Electronics*, pp. 47–53; March, 1957. *Elect. Commun.*, pp. 93–102; 1958.)

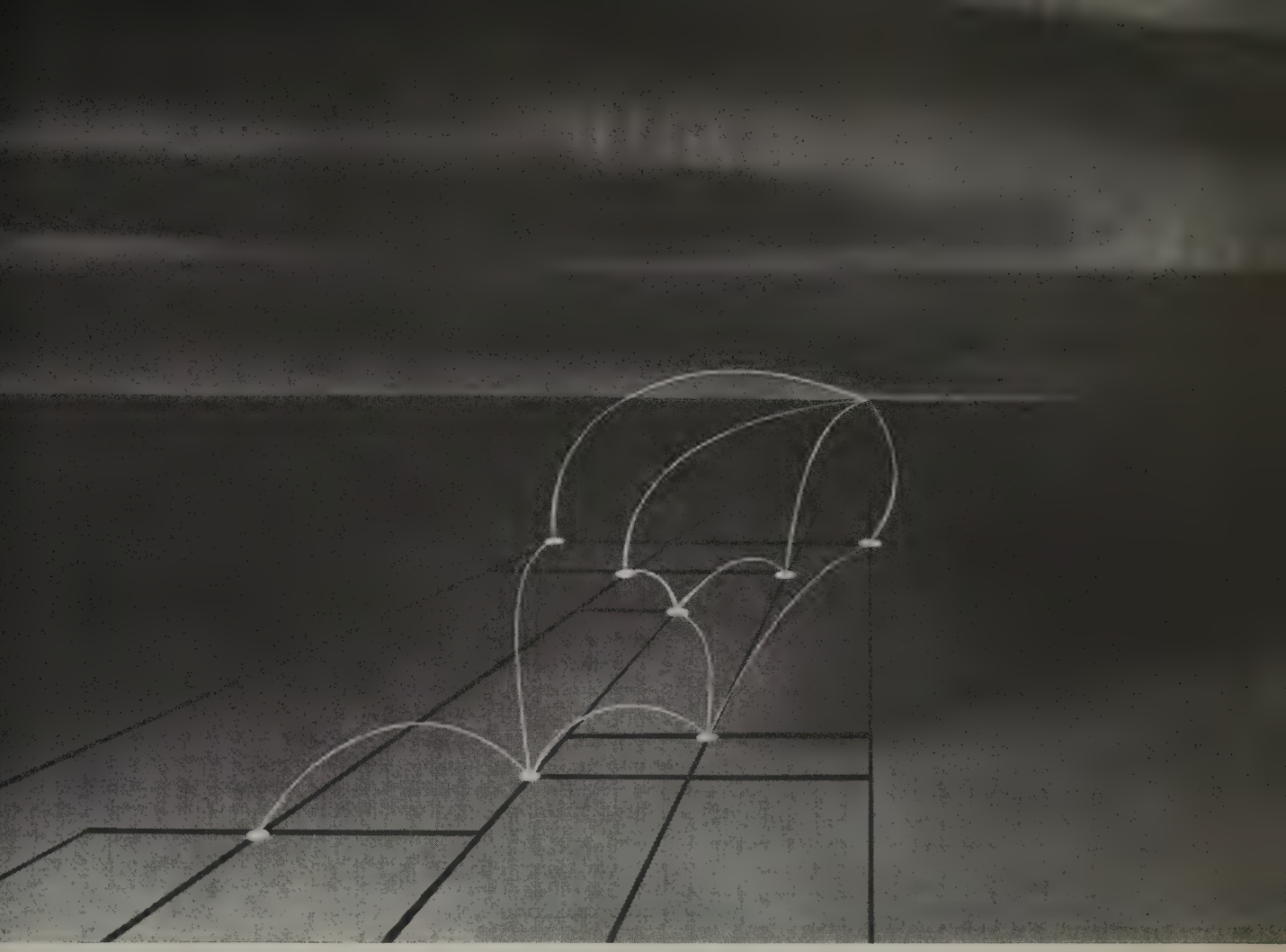
621.385.832 1747
Cathode-Ray Tube Adds Third Dimension—E. L. Withey. (*Electronics*, vol. 31, pp. 81–83; May 23, 1958.) Details are given of the "peritron," an experimental crt in which the fluorescent screen, of 18-cm diameter, is displaced harmonically along the Z-axis using a drive motor and crank assembly. A sinusoidal signal relating to the instantaneous position of the screen and derived by means of a magnet mounted in the push-rod and a fixed coil, is used to provide beam gating and focusing correction. Applications in air-traffic control systems are discussed.

621.385.832.087.6 1748
An Electron-Beam Tube for 'Writing' Directly on Special Paper—(*Elektronik*, vol. 7, p. 48; February, 1958.) The prototype tube described has numerous short lengths of wire incorporated in its glass screen with the bare wire ends protruding slightly from the screen to form a raster. The electron beam impinging on the inner end of the wires will leave a record of its trace on current-sensitive paper (Type L, teledeltos) placed in contact with the tube screen.

MISCELLANEOUS

061.4:621.3 1749
Physical Society's Exhibition [1959]—(*Wireless World*, vol. 65, pp. 126–134; March, 1959.) Brief descriptions are given of selected exhibits.

621.3-71 1750
Prediction of Temperatures in Forced-Convection-Cooled Electronic Equipment—L. Fried. (IRE TRANS. ON COMPONENT PARTS, vol. CP-5, pp. 102–107. Abstract, PROC. IRE, vol. 46, p. 1553; August, 1958.)



Report from IBM *Yorktown Research Center, New York*

ORGANIZING A MAXIMAL-SPEED COMPUTER

In designing a computer suitable for extremely high information-processing rates, it becomes necessary to re-examine basic concepts of machine organization in the light of new devices, new programming techniques and new applications. This study is being conducted by a machine organization group at the IBM Yorktown Research Center.

Investigations into the principles of computers are leading to the design of a completely superconducting machine. Its computing speed and capacity will be so high that the finite velocity of propagation of electromagnetic signals becomes the limiting speed factor. Therefore, the design must not only provide for the unique properties of superconductors but must minimize the effects of information transmission delays. This will be accomplished by a machine organization which causes information to be confined in packets as it is processed through the machine, and by the use of miniature circuits. In addition, the machine will provide the facility for simultaneous or parallel calculations of different parts of a problem. Furthermore, whereas most machines have been synchronous (in that information flow is controlled by traffic signals operated by a common clock), methods of completely asynchronous operation are now being investigated.

A machine such as this superconductor computer may well lead to important theoretical advances in many scientific fields. This study is part of a broad research program in computer organization extending the mathematical theories of computers and their application to information processing systems of all kinds.

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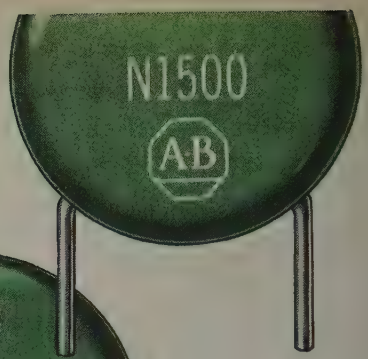
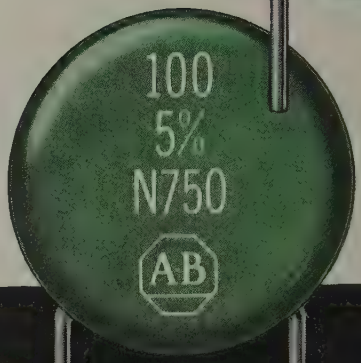
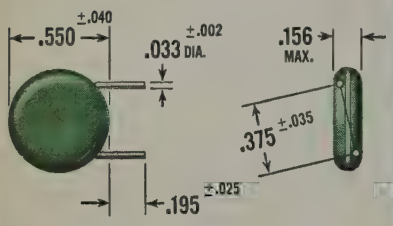




A-B QUALITY

ACTUAL SIZE TYPE A CAPACITORS

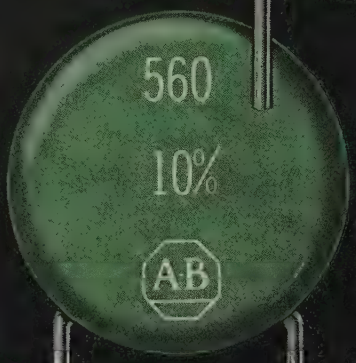


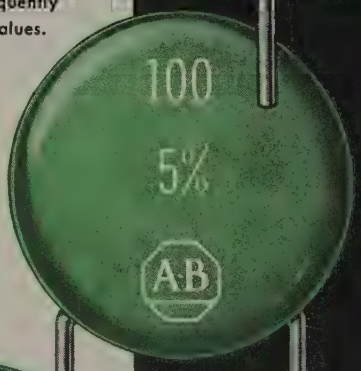
Allen-Bradley Type A capacitors are available in the most frequently used types and capacitance values.

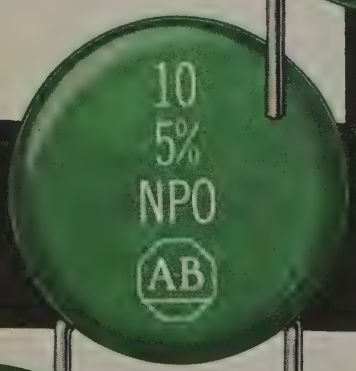
General Purpose Type in capacitance values from 10 mmf to .01 mmf.

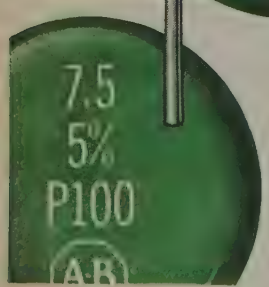
Stable Type in capacitance values from 10 mmf to 0.1 mmf.

Temperature Compensating Type in characteristics from N4700 to P100, and in capacitance values from 10 mmf to 510 mmf.









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Compare the attractive Allen-Bradley Type A ceramic capacitors with all the rest... you'll see instantly why more and more engineers are specifying them and will not accept substitutes —because there aren't any! The exclusive "Auto-Coat" process makes possible—for the first time—a capacitor of real beauty, precise physical uniformity, plus consistent and reliable quality and performance.

The smooth, tough insulating coating and the inherent mechanical uniformity of Type A capacitors permit easy hand or accurate automatic insertion on printed boards. Also, the "Auto-Coat" process prevents rundown on leads—costly wire cleaning and crimping to prevent soldering failures are unnecessary.

For full information on the *superior* physical and electrical properties of A-B Type A capacitors, send for Technical Bulletin 5401.

ALLEN-BRADLEY

Quality Electronic Components

Allen-Bradley Co., 114 W. Greenfield Ave., Milwaukee 4, Wis.
In Canada: Allen-Bradley Canada Ltd., Galt, Ont.

HOW TO MEASURE ATTENUATION

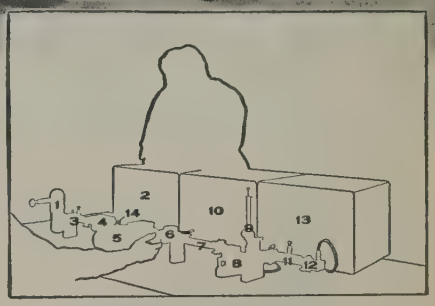
This microwave bench set-up is for the measurement of attenuation by the RF SUBSTITUTION method. Other techniques could have been shown, but this represents one of the simplest, easiest to use methods known.

The one main point we would like to stress is: regardless of the kind of measurements made, the quality of the test equipment used is of the utmost importance. That's why PRD has concentrated on producing the **widest** range of the **most precise** microwave test equipment available anywhere in the world.

In the RF SUBSTITUTION method, the PRD 195-B Precision Gauge Attenuator is used as a standard and calibrated for the frequency at which the attenuation is to be measured. The PRD 195-B is set at some value of attenuation greater than the unknown. Its reading and the output power level of the line shown on the PRD 650-B Power Bridge are both recorded. The unknown is then inserted into the line thereby changing the output level, and the PRD 195-B is readjusted to return the power level to its original value. The attenuation of the unknown is simply the difference between the two readings of the PRD 195-B.

Sound Simple? Sure it is, but even more important it's accurate. The PRD 195-B has a guaranteed calibration accuracy of ± 0.2 db.

The precision and ease of operation of all of the products shown in this example are typical of each of over 300 PRD microwave test instruments currently produced. For detailed specifications of the products shown in the measurement bench, write:



TEST INSTRUMENTS USED IN THIS X-BAND ATTENUATION BENCH

1—703 Shielded Tube Mount, catalog page F-8
2—809 Klystron Power Supply, catalog page F-10
3—303-A Slide Screw Tuner, catalog page B-14
4—1203 Waveguide Ferrite Isolator, catalog page A-21
5—535 Frequency Meter, catalog page D-12
6—195-B Precision Gauge Attenuator, catalog page A-5
7—UNKNOWN represented by a 140 Fixed Waveguide Attenuator, catalog page A-11
8—203-D Slotted Section, catalog page B-11
9—250-A Broadband Probe, catalog page B-12
10—277-A Standing Wave Amplifier, catalog page E-7
11—303-A Slide Screw Tuner, catalog page B-14
12—643 Waveguide Thermistor Mount, catalog page E-9
13—650-B Power Bridge, catalog page E-13
14—159-A Level Set Attenuator, catalog page A-17

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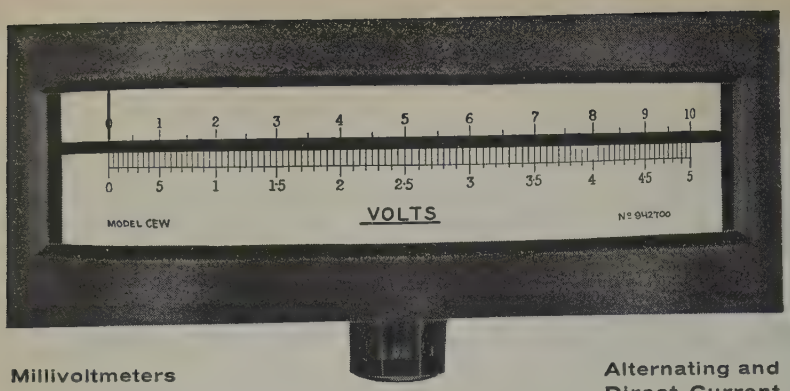
West Coast Office: 2639 So. La Cienega Blvd., Los Angeles 34, California. Telephone: TExas 0-1940

Special problems in attenuation and other related measurements? Contact our Applications Engineering Department.



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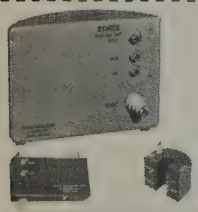
MISSILE AND RADAR
STANDARD DC POWER SUPPLIES

MISSILE-GROUND

Perkin has developed Tubeless Magnetic Amplifier Regulated DC Power Supplies for missile launching and check-out, with ratings (@ 24-32 volts) of 30 to 500 amperes: with provisions for rack panel mounting and remote sensing. Perkin ground power supplies are now being used in the *Thor, Atlas, Bomarc, Vanguard* and other missile programs.



RADAR-AIRBORNE

There are more than 6,000 Perkin units operating in Military and Commercial Radar Systems. Ratings from 6 to 12KV are available. Nominal AC input frequency is 400 cps; Temperature Range—up to +125°C and above. Typical Weight: 2 lbs. No tubes, moving parts or vibrating contacts; epoxy resin potted.

RADAR-GROUND

Hundreds of Perkin Ground Radar Systems are in operation throughout the country. Built to MIL-E-4158. Typical unit is rated at 24-32 volts @ 100 amperes, ±½% regulation and 1% rms ripple. All units conservatively designed.

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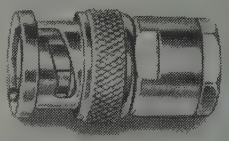

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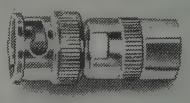

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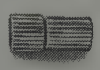

MINIATURE?

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Unit engineered to fit all available sub-miniature cables, AUTOMATIC'S Sub-Miniature Connectors are available in three types; BAYONET, PUSH-ON AND THREADED COUPLING.

Special receptacles available for printed circuit applications.

CHECK THESE FEATURES:

No special tools required for assembly. Foolproof clamping insures accurate alignment . . . positive contact . . . extra strong grip. Exclusive internal-parts design allows outside dimensions of connectors to remain constant regardless of cable dimensions.

For BAYONET, PUSH-ON and THREADED SUB-MINIATURE and MICRO-MINIATURE COAXIAL CABLE CONNECTORS, always specify AUTOMATIC. Our engineers are always ready to discuss your special requirements.

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Your further inquiry is invited.

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NEW ENGINEERING IMPROVEMENTS THROUGHOUT!

- Faster slewing speeds— Pen: 30"/sec.; Carriage: 30"/sec.
- Greater accuracies— Static: 0.1%; Dynamic: 0.2%.
- 0.05% internal calibration.
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- New improved vacuum hold-down system.
- Vernier control between ranges.
- Input function modules in rack mountable case can be removed from plotter for remote operation.
- Calibrated scales on both axes.
- Front panel gain control.
- Vacuum release on front panel.
- Visible ink supply.

One basic plotter with input modules available for general purpose, computer, low level differential, time base, curve following and other specialized functions.

	Model 410 Computer Module	Model 420 General Purpose Module	Model 430 Low Level Differential Module	Model 450 Curve Follower Module	Model 460 Time Base Module
Input	Single Ended	Single-Ended	Differential	Single-Ended	Single-Ended
Ranges	0.1, 1.0, 10v/in, calibrated vernier	16 steps, 1m v/in to 100 v/in, plus vernier	16 steps, 1m v/in to 100 v/in, plus vernier		0.1, 0.2, 0.3, 0.6, 1.0, 2.0 in/sec
Accuracy: Static Dynamic	±0.1% F/s ±0.2% F/s	±0.1% F/s ±0.2% F/s	±0.15% F/s ±0.2% F/s	±0.25% F/s	(time) ±1.0% F/s
Linearity				±0.1% F/s	(sweep) ±0.5% F/s
Input Resistance	2 megs, all ranges	1 meg to 3 megs Depending on range	1 meg to 3 megs Depending on range		
Zero Adjust	Full scale X and Y plus 9" offset	Full scale X and Y plus 9" offset	Full scale X and Y plus 9" offset		
Reference	Internal Zener diode and external ±100v computer	Internal Zener diode	Internal Zener diode		Internal Zener diode
Calibration	Internal 0.1, 1.0, 10v Accurate to ±0.05%				
Common Mode Rejection			DC, 120 db AC, 100 db at 60 cps		
Max. Common Mode Voltage			50 v dc or peak ac		
Principle of Operation				60 cps magnetic induction	Electronic integration
Zero Drift				None	

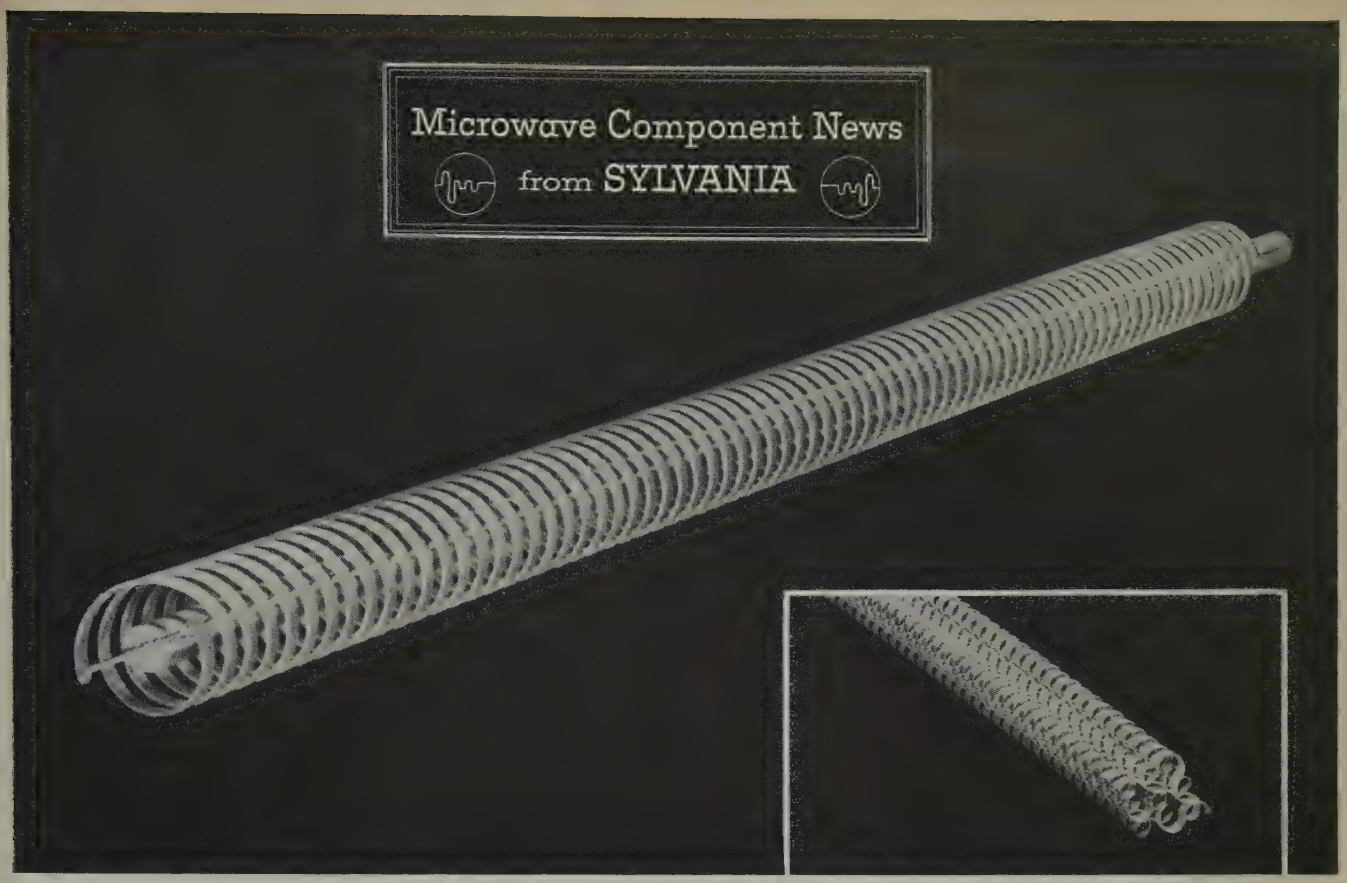
Dimensions All Modules: 8½" W x 3½" H x 7¾" D

Model 400 Plotter

Recording Size: 10" x 15"
Slewing Speed: X, 40"/sec; Y, 30"/sec
Inputs: X and Y inputs, and computer reference
Power: 115 ±10 v, 60 cps
Dimensions: 19" W x 19½" H x 11¾" D
Ambient Temperature Range: 0-55°C
Controls: Power off, standby, operate, pen; vacuum release; curve follower, amplifier; local, remote.

3540 Aero Court
San Diego 11, California

Electro Instruments, Inc.



Sylvania research in circuit "Components" paves the way for better microwave systems

Recognize these special traveling wave tube helices? They were developed through Sylvania's programs of applied research and product development in the continuing search for better microwave components.

Beams and Microwaves—Sylvania has accumulated unequalled experience in the study of the interplay between electron beams and microwaves.

"Better Power-Bandwidth in TWT's"

The development of a Traveling Wave Tube with essentially flat power-bandwidth is a classic example of the progress being made through the theoretical investigation of microwave components viewed as RF circuits.

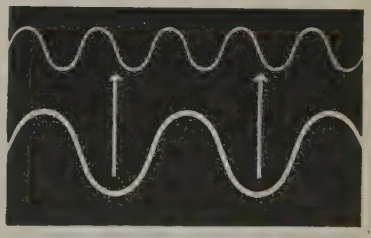
This experience will play a vital role in realizing the full potential of the beam approach to parametric amplifiers, which offers a theoretical noise level of zero.

Major strides are also being made in klystrons, backward-wave magnetrons (Carcinotrons), and low-noise backward-wave amplifiers.

"Communicating with missiles in flight"

Plasma and Microwaves—Sylvania is also making thorough studies of the interplay between plasmas and microwaves. This area holds the secrets of getting communications through shock waves and exhaust of missiles in flight. And, it provides direction for the development of new microwave components such as high-speed switches and harmonic generators.

Solid State and Microwaves—Important new research promises better power sources for higher frequencies through harmonic generation, using ferrites. The work has already yielded new ferrite isolators and circulators; microwave control devices are in the development stage.



"Harmonic Generation"

What are your Special Requirements? Sylvania research and development facilities can be applied in any of these areas to meet your special requirements. We welcome the opportunity to meet with you. Write us at the address below.

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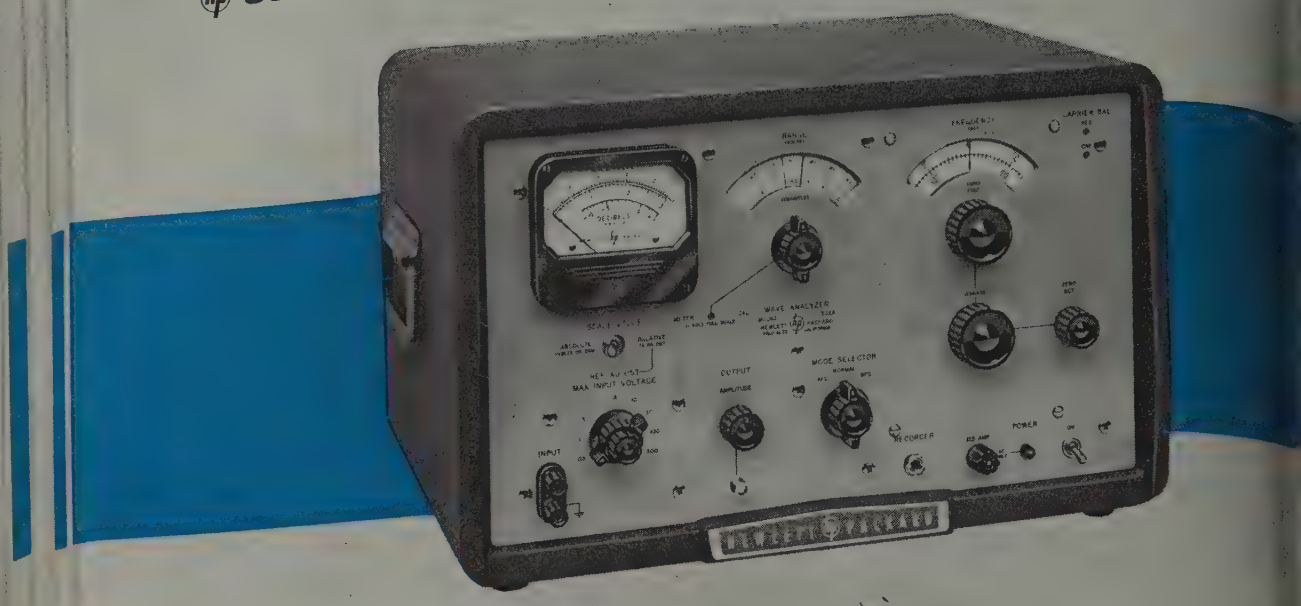
These pages from the new hp catalog in WAVE ANALYZERS in 10 years!

hp 302A WAVE ANALYZER



New, Transistorized — Directly Measures Wave Components

Advantages:

- No calibration or stabilization needed
- Direct readings; accurate
- Measures frequencies 20 cps to 50 KC
- Completely transistorized
- Battery or ac powered; hum free
- Low power consumption; no warm-up needed
- Very sharp acceptance circuits
- AFC; also frequency restorer circuit
- Compact, rugged, versatile

Uses:

Measures and analyzes fundamentals, harmonics, and intermodulation products in telemetering, carrier and vibration systems as well as audio circuits. Speeds analysis of noise and broadcast amplifier characteristics; modulation amplifier, film sound track and recording distortion; hum, network characteristics, etc.

NEW MODEL 302A Wave Analyzer represents a significant improvement in wave analyzer design. Completely transistorized, sophisticated in design, highly selective, free of tedious calibration and stabilization before use—these are but a few of the important convenience and accuracy features in the new 302A.

Other exceptional features are low power consumption (in the order of 3 watts), provision for battery operation (18 to 28 volts) as well as ac line power, and elimination of warmup time.

Simple Operation

In operation the instrument functions as a highly selec tive tuned voltmeter. A front panel control selects the fre quency to be measured and voltage is then read directly o the front panel meter.

Basically, Model 302A functions by separating an inpu signal into individual components so that each—the fun damental, harmonics and any intermodulation products— may be evaluated separately.

The instrument operates by mixing the input signal wit an internal oscillator adjusted to provide a difference fr quency of 100 KC. An automatic frequency control circu maintains a constant difference frequency between the i put and oscillator signals. This insures accurate measur ments despite frequency drift in the input signal. Aft modulation by a voltage from the internal oscillator t

announce the first major improvement

signal is passed through a narrow-band crystal filter, amplified and metered.

Frequency Restorer

A frequency restorer circuit makes accurate frequency measurements possible at each component's frequency of the input wave. This circuit supplies a sinusoidal signal at the frequency of the specific component which can be measured on an electronic counter or observed on an oscilloscope. The amplitude of this signal is determined by the level of the selected component. When the mode selector switch is in the normal or AFC position, the signal appears at the output terminals if the meter is indicating.

Model 302A is also particularly useful for measuring small signals on noisy systems or transmission lines. When the mode selector is switched to "BFO" the instrument becomes an oscillator and tuned voltmeter automatically tuned by one control to the same or oscillator frequency. The selective tuned voltmeter then discriminates against the noise and measures the desired signal.

Speed and accuracy of measuring is enhanced by a linearly calibrated tuning control giving the same "tuning feel" throughout range.

Basic Laboratory Instrument

Covering the frequency range of 20 cps to 50 KC, the new hp 302A is equipped to perform a wide variety of daily measurements. It has broad usefulness not only in audio measurements but in vibration work, telemetry, and carrier applications. The instrument is compact, rugged and features conservative design and high quality throughout.

Specifications

Frequency Range: 20 cps to 50 KC.

Frequency Calibration: Linear graduation 1 division per 10 cycles. Accuracy ±(1 % + 5 ~).

Voltage Range: 3 μv to 300 v, full scale readings of:

300 v	300 mv	300 μv
100 v	100 mv	100 μv
30 v	30 mv	30 μv
10 v	10 mv	
3 v	3 mv	
1 v	1 mv	

Ranges provided by an input attenuator switch and a meter range switch in steps of 1:3 or 10 db. Meter range is indicated by a dial mechanically linked to input attenuator. An absolute-relative switch, in conjunction with a variable 10 db control is provided for adjustment of intermediate values.

Warm-Up-Time: None.

Voltage Accuracy: ±5% of full scale value.

Residual Modulation Products and Hum Voltage: Greater than 75 db down.

Intermediate Frequency Rejection: Intermediate frequency present in input signal rejected by at least 75 db.

Selectivity: ± 3½ cycle b.w.—at least 3 db down
± 25 cycle b. w.—at least 50 db down
± 70 cycle b.w.—at least 80 db down
beyond ± 70 cycle b.w.—at least 80 db down

Input Impedance: Determined by setting of input attenuator: 100,000 ohms on 4 most sensitive ranges, 1 megohm on remaining ranges.

Selected Frequency Output: 1 v open circuit at output terminals for full scale meter deflection. Output level control provided. Frequency response ±1 db, 20 cycles to 50 KC. Output impedance approximately 600 ohms.

B. F. O. Output: 1 v open circuit at output terminals. Output level control provided. Frequency response ±1 db, 20 cps to 50 KC. Output impedance approximately 600 ohms.

Automatic Frequency Control: Range of frequency holdin is ±100 cycles minimum.

Power: 115/230 v ±10%, 50/1600 cycles, 3 watts (approximately). Terminals provided for powering instrument from external battery source. Battery supply range 28 v to 18 v.

Weight: Net 43 lbs. Shipping 63 lbs. (cabinet mount). Net 35 lbs. Shipping 55 lbs. (rack mount).

Dimensions: Cabinet Mount: 20¾" wide; 12½" high; 14½" deep. Rack Mount: 19" wide; 10½" high; 13½" deep.

Price: $1,475.00 (cabinet); $1,460.00 (rack mount).

Data subject to change without notice.

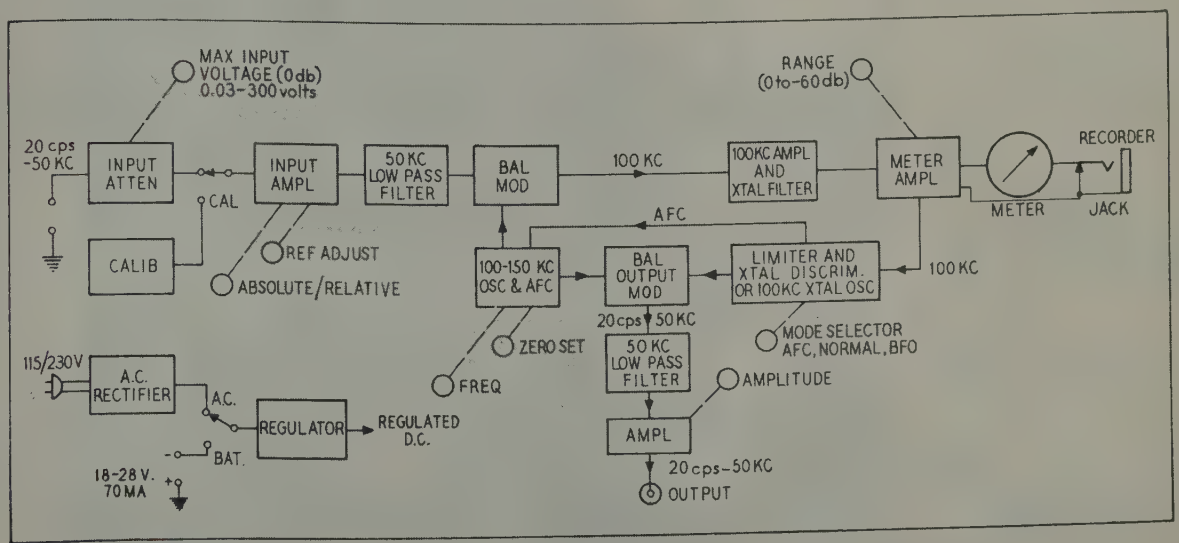


Figure 1. Block diagram, Model 302A Harmonic Wave Analyzer

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.3% Max. Lifetime Drift

RELIABLE
"Built-in" Quality Construction

"SILICOHM" TYPE S • Axial Lead Units (2-10 Watts) (.1 to 175,000 ohms) to MIL-R-26C (Insulated) Specifications, Char. G.

"SILICOHM" TYPE M • Metal-Clad (Chassis-Mounted) Units (10-25-50 Watts) (.1 to 175,000 ohms) to MIL-R-18546B (Ships) Specifications—Char. G.

WRITE FOR DESCRIPTIVE LITERATURE

SAGE
ELECTRONICS CORPORATION
P.O. BOX 126, ROCHESTER 10, N. Y.

IRE People

(Continued from page 92A)

air-to-air guided missiles now carried by U. S. and Canadian Air Force all-weather jet interceptors.

Previously he held engineering and management positions with A. B. DuMont Laboratories, Massachusetts Institute of Technology radiation laboratory, and the U. S. Signal Corps.

He was graduated from Massachusetts Institute of Technology in 1939 with the B.S. degree in electrical engineering. He also did graduate work at Stevens Institute of Technology. He has published many technical papers and holds patents in pulse circuits, television, and automatic control. He is author of a textbook entitled "Mathematics for Radio Engineers."

He is a member of Eta Kappa Nu.

❖

The Thompson-Ramo-Wooldridge Products Company has announced the establishment of a field engineering office in Port Arthur, Texas, to provide services to the company's customers in the Port Arthur area. **Eugene C. Swanson** (S'55–M'57) has been placed in charge of the office.

Previously a computer maintenance engineer for the Computer Control Company, Point Mugu, Calif., Mr. Swanson has been with Thompson-Ramo-Wooldridge Products since August, 1958. He has completed extensive training in the operation, programming, installation, and maintenance of the RW-300 Digital Control Computer, and has participated in the check-out and testing of these computers.

He holds a B.S. degree in electrical engineering from the University of California.

❖

G. W. Sioles

George W. Sioles (M'52), acoustics engineer, has been named group leader for transducer research in the Acoustics and Magnetics Department of the new CBS Laboratories, Stamford, Conn., a division of the Columbia Broadcasting System, Inc.

Mr. Sioles was formerly project engineer specializing in the development of loudspeakers and their enclosures for University Loudspeakers, Inc., White Plains, N. Y., and had served as project engineer on navigational training aides at the U. S. Navy Special Devices Center at Port Washington, N. Y. He is a member of the Acoustical Society of America, the IRE Professional Group on Audio and the Audio Engineering Society.

❖

"QUICK LOOK" Antenna Pattern Display
MODEL APD-1

In one unit, either polar or rectangular coordinates; either log, linear or square root response

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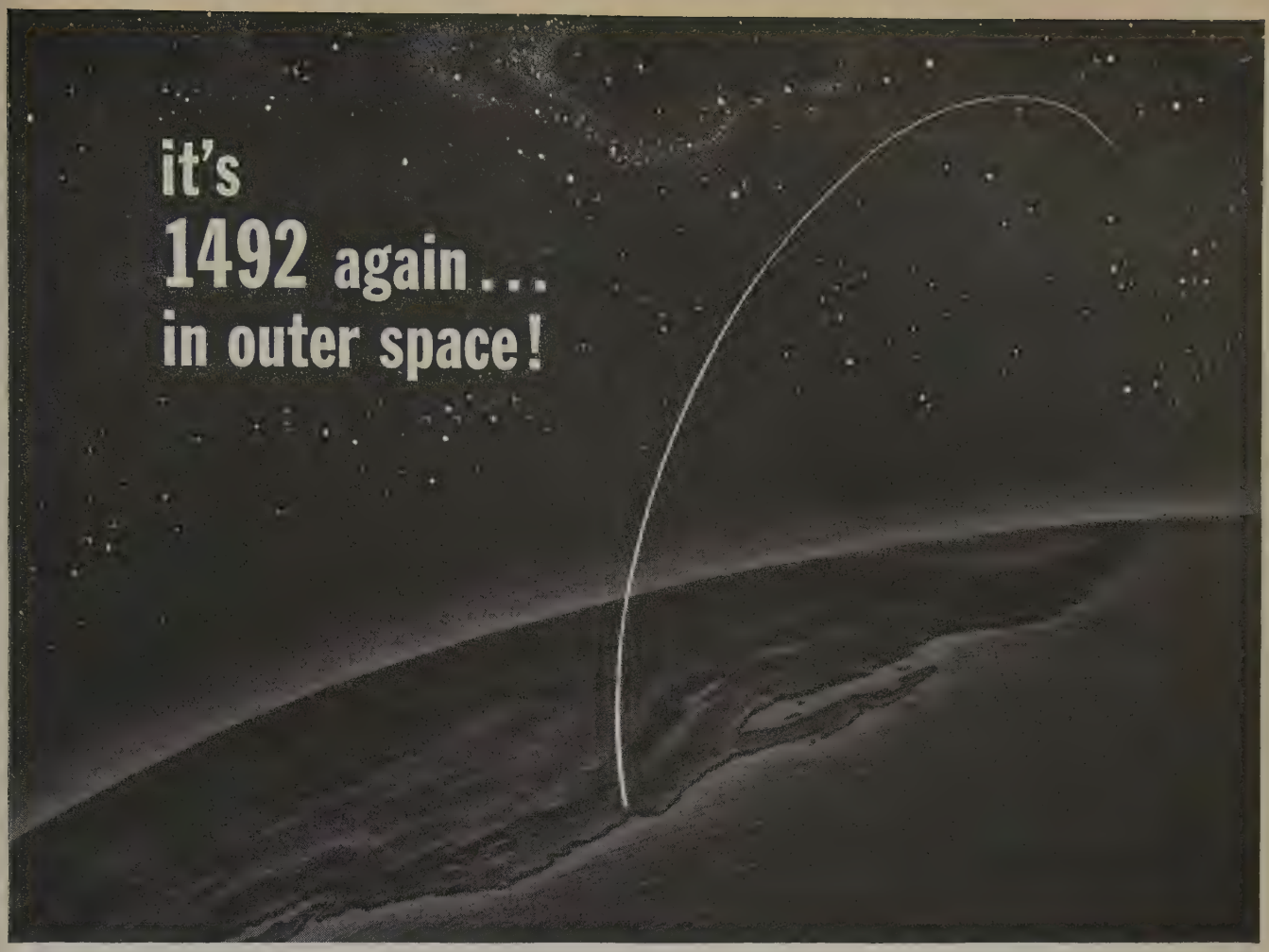

Philco Ground-Space Communications System commands and tracks **DISCOVERER** satellite

DISCOVERER . . . the United States' newest earth satellite . . . is opening new vistas on the frontier of outer space. And Philco is proud to play an important role in this renowned achievement as a part of the Discoverer Team . . . in conjunction with the Lockheed Aircraft Corporation and the Air Force at the direction of the Advanced Research Projects Agency of the Department of Defense.

As the subcontractor for Discoverer's entire communications system, Philco designed and developed the vast complexity of ground-space communications, tracking, commanding and data gathering and processing systems.

The Philco-designed and equipped system observes and commands Discoverer through a series of five tracking and data collection stations in Alaska, California, Hawaii and a specially equipped ship at sea. Philco continues its participation in the Discoverer Program by assisting in the actual operation and maintenance of the communications and data handling network.

Philco's part in the Discoverer Program is typical of the many and diverse advanced research and development activities being conducted in our laboratories on the East and West Coasts where outstanding career opportunities abound for Engineers, Mathematicians, and Physicists.

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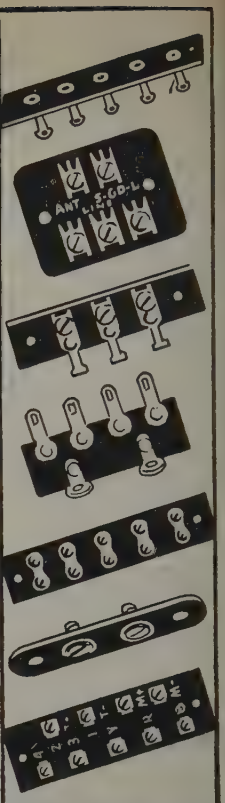

Several pages of Jones Catalog No. 22 illustrate standard and special panels we are constantly producing. Latest special equipment enables us promptly to produce practically any panel required. Send print or description for prices, without obligation. Hundreds of standard terminal strips also listed. Send for Catalog, with engineering drawings and data.

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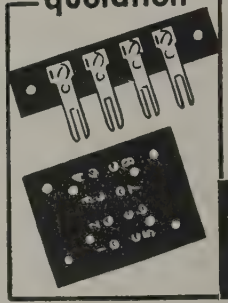
Send your specifications for prompt quotation



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CINCH MANUFACTURING COMPANY
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DIVISION OF UNITED-CARR FASTENER CORP.

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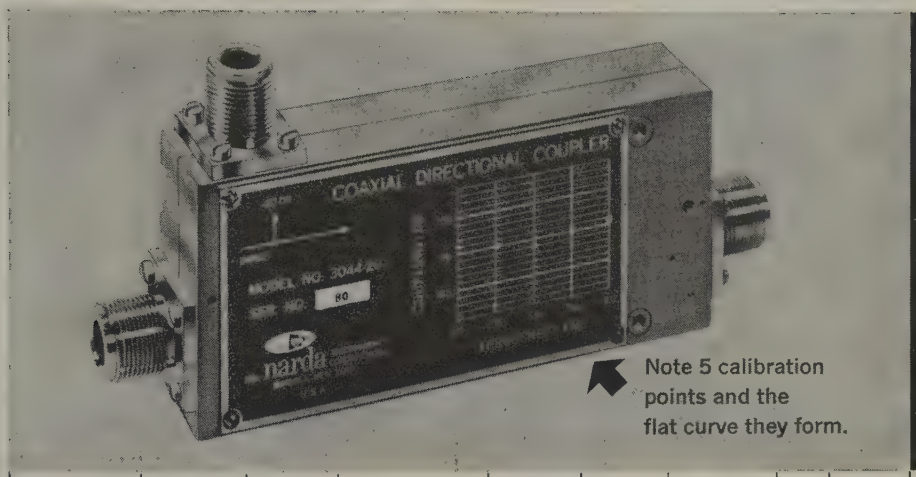
NEW FROM NARDA

THE INDUSTRY'S FLATTEST COAX COUPLER!

Only 0.2 db variation over full octave!

What more is there to say? The new series of Narda Coaxial Couplers is absolutely the flattest on the market; the specs are here; the prices are here. And you know Narda's reputation for quality! If you need a really flat coupler, contact your Narda representative, or write to us directly.



Note 5 calibration points and the flat curve they form.

Coupling Characteristics

Frequency Response	±0.2 db
Deviation of Mean Value from Nominal	±0.3 db
Calibration Accuracy	±0.1 db

Calibration points at 5 frequencies

Connectors: Series N female; others on special order.

Frequency (mc)	Nominal Coupling	NARDA Model	VSWR Primary, VSWR Secondary	Minimum Directivity (db)	FORWARD (watts)	Power Rating REV. (watts)	PK. (kw)	Price
240-500	20	3040-20	1.1/1.2	20	1000	100	10	
500-1000	20	3041-20	1.1/1.2	20	1000	100	10	
950-2000	20	3042-20	1.1/1.2	20	1000	100	10	
2000-4000	20	3043-20	1.15/1.2	20	1000	200	10	$200
4000-8000	20	3044-20	1.2/1.25	17	1000	200	10	
7000-11,000	20	3045-20	1.25/1.3	15	1000	200	10	

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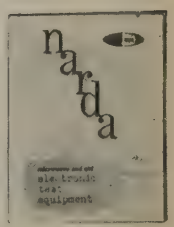
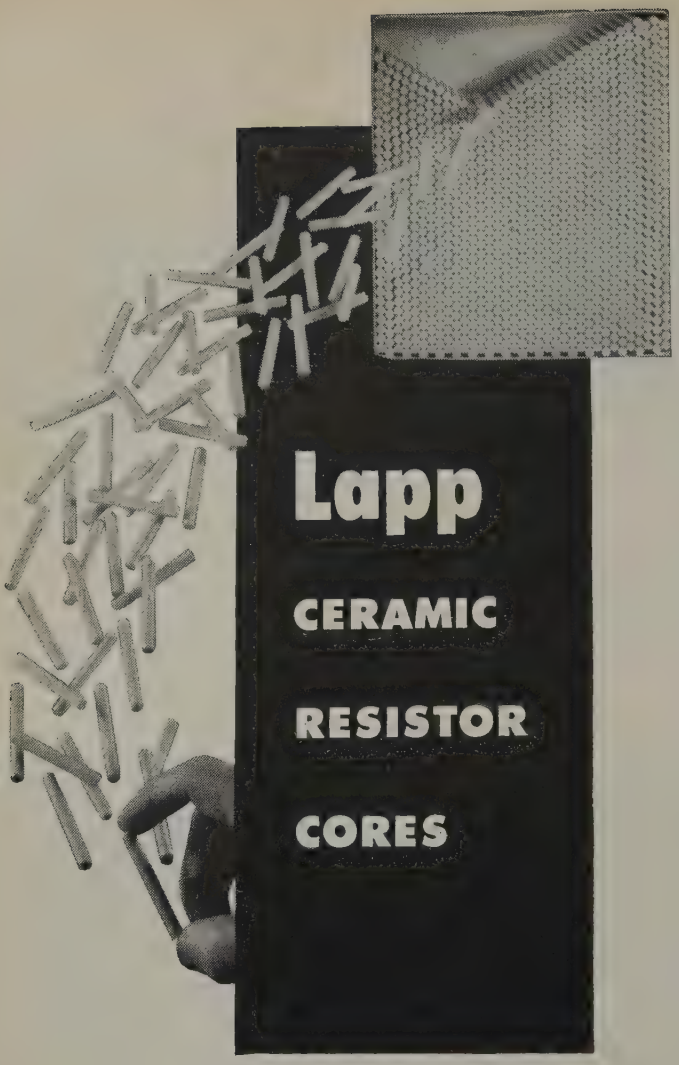


the narda microwave corporation

118-160 HERRICKS ROAD, MINEOLA, L. I., N. Y. • PIONEER 6-4650



A special porcelain body is used in the production of Lapp Resistor Cores. It provides a flawless surface of such nature as properly to receive a uniform deposit of carbon or boro-carbon. It also has a temperature coefficient of expansion matched to that of the deposited film . . . to provide a constant resistance against temperature change. These resistor cores are produced in close tolerances for straightness, roundness and length . . . they reflect the same quality of workmanship and materials long associated with Lapp. Write for complete information on Lapp Resistor Cores. Lapp Insulator Co., Inc., Radio Specialties Division, 218 Sumner St., LeRoy, N. Y.

Lapp

Professional Group Meetings

Aeronautical and Navigational Electronics

Philadelphia—March 3

"Tracking Gates for Air Traffic Control Surveillance Radar," G. Fernsler, and A. Frank, Philco Corp.

Antennas and Propagation

Akron—March 12

"Analogies between Sonar Transducers and Antennas," H. Miller, Clevite Res. Center.

Akron—April 9

"An Extension of the Dolf-Chebyshev Antenna Concept," R. L. Mattingly, Bell Tel. Labs.

Boston—March 4

"The Effect of the Aurora on UHF Propagation," J. H. Chisholm, M.I.T. Lincoln Lab.

Los Angeles—March 12

"Antenna Radiation Pattern Range, Scale Model Techniques and Management," T. Hancock, Lockheed Aircraft Corp.

"JPL's Space Vehicle Tracking Station," K. Linnes, Jet Propulsion Lab.

Antennas and Propagation Microwave Theory and Techniques

Philadelphia—March 18

"A Two Cavity Unilateral Maser Amplifier," N. Sher, Philco Corp.

Audio

Boston—March 19

"Hi-Fi" Standards, D. R. Von Recklinghausen, H. H. Scott, Inc.

Philadelphia—March 11

"Stereophonic Disc Recording and Reproducing Techniques," W. S. Bachman, Columbia Records.

Automatic Control

Baltimore—March 19

"Cobalt 60 Rotational Teletherapy Controls," R. Riley, Westinghouse Elec. Corp.

Los Angeles—March 10

"Optimum Synthesis of Multipole Control Systems with Random Processes as Inputs," C. T. Leondes and Hsien-Chiang Hsieh, U. C. L. A.

(Continued on page 118A)

KEARFOTT PRECISION RESOLVERS FOR EVERY SYSTEM APPLICATION

Kearfott has available a complete line of precision resolvers for every system application. Computing resolvers range in functional accuracy from 0.1% to .005%, in bridge accuracy from 5 minutes to 20 seconds of arc and in size from 11 to 25. Non-compensated resolvers range from 5 minutes to 20 seconds of arc in accuracy, from 8 to 25 in size.
All Kearfott resolvers feature stainless housing, shafts and bearings and corrosion-resistant lamination materials for maximum environmental resistance. Optional designs available for operation at 200°C and in environment of 2000 cps vibration at 30 g's.

Computing Resolvers

Available with integral compensating windings. Can be provided with trimming networks to match existing isolation amplifiers or Kearfott-designed transistorized amplifiers.

Size 11

For applications where size and good functional accuracy are of paramount importance. Functional accuracy as good as 0.1% and bridge errors of 3 minutes of arc are in production.

Size 15

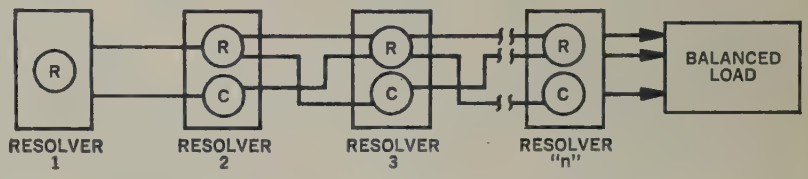
A 2:1 improvement in functional accuracy obtained in this configuration. Unit tabulated is the direct equivalent of standard Navy BuOrd Mark 4 Mod 3 and contains necessary trimming network for standard buffer amplifiers. Transformation ratio is 1.000 ± .0001, phase shift 0° ± 1 minute. Functional accuracy of .05% and bridge error of 3 minutes of arc are standard.

Size 25

For applications demanding the highest order of accuracy. Close attention has been paid to design parameters.

Size 18

A special resolver which permits a unique cascading of these units without the necessity for buffer amplifiers. Typical application is illustrated in following cascade:



R=RESOLVER C=INTEGRAL COMPENSATOR

COMPENSATED RESOLVERS FOR PRECISE COMPUTER APPLICATIONS

SIZE	11		15	18	25
PART NUMBER	R980-01	R980-41	T980-51	V980-004	425506-1
Excitation Volts—(Max.)	60	60	26	26	115
Excitation Volts (Test)	10	10	15	13	25
Frequency—(cps)	400	400	400	400	400
Primary Impedance	629 + j2510	450 + j2200	220 + j1000	3000 + j (0 ± 40)	1630/78.5°
Secondary Impedance	695 + j2750	500 + j2300	240 + j1100	3000 + j (0 ± 40)	1620/80°
Transformation Ratio (Primary to Secondary)	.980	.980	.980	.775	.980
Transformation Ratio (Compensator to Rotor)	.985	.985	.950	.775	.985
Phase Shift (Lead)	8.5°	7.5°	8.5°	0° ± 10'	2.1°
Fundamental Null (MV)	15	15	8	15	15
Bridge Error From E.Z. (Max.) Primary	*7 mins. Stator	*5 mins. Stator	*5 mins. Stator	3 mins. Stator	0.7 mins. Stator

*Also available 3 mins. from E.Z.

Non-Compensated Resolvers

Basically for application in precise data transmission systems. These synchro resolvers permit system designer to achieve system errors of better than 1 minute of arc without using 2-speed servos and elaborate electronics. By proper impedance matches up to 64 resolver control transformers can also operate from one resolver transmitter.

Size 11

Where size is important. These units have a maximum unit error of 3 minutes of arc.

Size 25

Where highest accuracy is required. These units have a maximum error as low as 20 seconds of arc.

NON-COMPENSATED RESOLVERS FOR PRECISE DATA TRANSMISSION

	SIZE 11			SIZE 25		
Type Resolver	Transmitter	Differential	Control Transformer	Transmitter	Differential	Control Transformer
Part Number	R982-004	R982-002	R982-012	Z5161-001	Z5191-001	Z5151-003
Excitation Volts (Max.)	26	11.8	11.8	115	90	90
Frequency (cps)	400	400	400	400	400	400
Primary Impedance	170/77°	95/80.2°	2000/80°	400/82°	800/80°	8500/82°
Secondary Impedance	42/80.5°	110/75.7°	8000/76°	260/82°	900/80°	14000/82°
Transformation Ratio	.454	1.000	1.906	.7826	1.000	1.278
Max. Error from E.Z. Primary	3 mins. Rotor	3 mins. Stator	3 mins. Stator	20 seconds Rotor	20 seconds Stator	20 seconds Stator

Write for complete data.

KEARFOTT COMPANY, INC., LITTLE FALLS, N. J.
A subsidiary of General Precision Equipment Corporation
Sales and Engineering Offices: 1500 Main Avenue, Clifton, N. J.
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PRECISE COAXIAL TUNERS TUNE TO VSWR 1.000

200-4000 MCS.

DESIGNED FOR USE whenever extremely accurate RF power terminations are required. This laboratory type Coaxial Tuner will tune out discontinuities of 2 to 1 in coaxial transmission line systems or adjust residual VSWR to 1.000 of loads, antennas, etc. May also be used to introduce a mismatch into an otherwise matched system.

M. C. Jones Coaxial Tuner is designed for extreme ease of operation, with no difficult laboratory techniques involved. Reduces tuning time to a matter of seconds. Graduations on carriage and probe permit resetting whenever reusing the same termination.

SPECIFICATIONS

Impedance	50.0 ohms	
Frequency Range	Model 151N	200-1000 Mcs.
	Model 152N	500-4000 Mcs.
RF Connectors	EIA 7/8" 50.0 ohm Flange plus adapters to N female connector	
Power Rating	100 watts	
Range of Correction	VSWR as high as 2 may be reduced to a value of 1.000	

For more information on Tuners, Directional Couplers, R. F. Loads, etc., please write for 68-page Catalog No. 12 or see Electronics Buyers Guide or Electronic Engineers Master.

M. C. JONES ELECTRONICS CO., INC.

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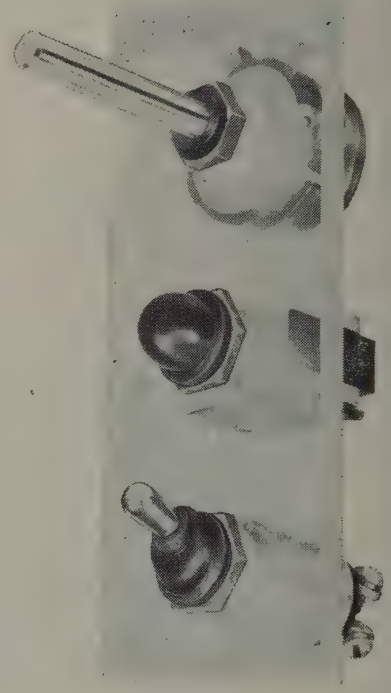
HEXSEALS®

Modular

(Explosion-Proof)*

SWITCH and SHAFT SEALS



- Fit all industrial electrical controls.
- Meet Military Specifications: MIL-B-005423A (ASG), MIL-B-19257 (Ships), SCL-6303 (Sig. Corps), Paragraph 183.10-20, Part (B) U.S. Coast Guard.

*DISCLAIMER: We cannot assume responsibility for explosion-proofing any equipment not entirely designed by APM, therefore no guarantee is made or implied.

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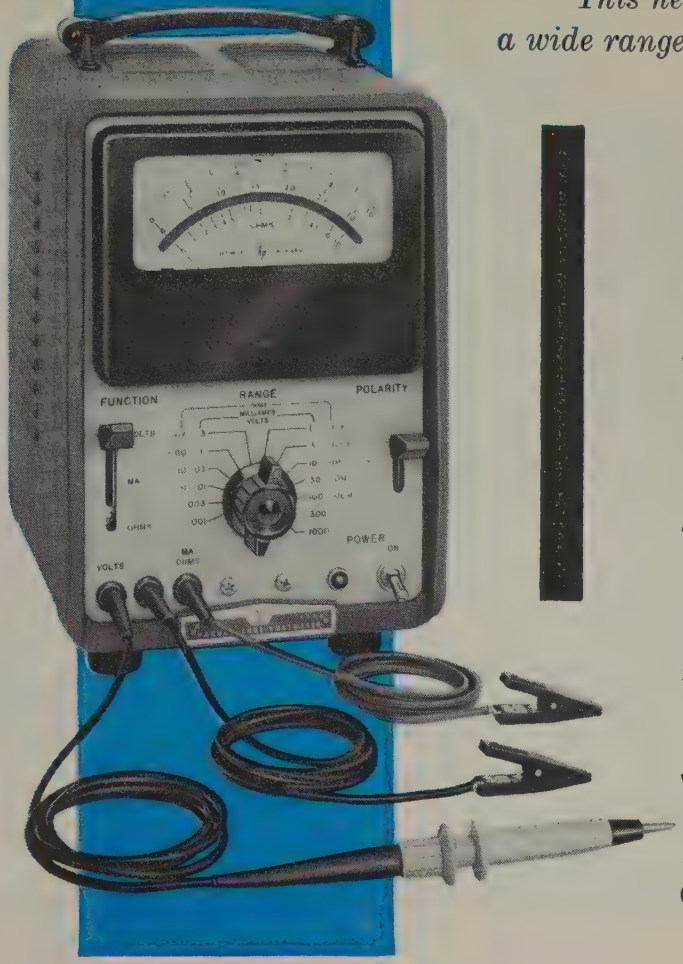
HIGH PRESSURE STATIC AND MOVABLE SEALS

HEXSEALS® • SEELSKREWS® • SEELBOLTS® • SEELRIVITS®

This new precision DC VTVM is also a wide range, precision ohmmeter and ammeter!



1% accuracy 100 μv to 1,000 volts!

Also 2% accuracy, 1 μa to 1 amp full scale.

Measures 0.02 ohms to 5,000 megohms.

No zero adjustment. 1 minute warm-up.

Floating chassis. $1,000 worth of convenience for $350!

Haven't you wished for one compact, simple instrument that would make *precision* dc voltage, dc current and resistance measurements over a wide range?

The new hp 412A is it! In its VTVM circuit, the 412A uses an exclusive hp photo-chopper instead of old-style mechanical vibrators—no drift, no 60 cps pickup. Input is floating, with resistance increasing from 10 megohms on the 1 mv range to 200 megohms on ranges above 100 mv. Current and voltage ranges have a 10 db sequence for maximum readability and overlap. The ohmmeter is a modified Kelvin bridge eliminating lead resistance error; you measure resistance accurately on hook-up wire sections as short as 6".

Model 412A also includes a 1 v or 1 ma recorder output, and 3 separate probes. Call your hp rep today for a demonstration on your bench. Price, $350.

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1001D PAGE MILL ROAD • PALO ALTO, CALIFORNIA, U.S.A.
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FIELD REPRESENTATIVES IN ALL PRINCIPAL AREAS

hp 400L LOGARITHMIC VOLTMETER—$325
New hp voltmeter covers 10 cps to 4 MC; accuracy high as ±2% of reading or 1% of full scale. Voltage range 0.3 mv to 300 v, 12 ranges, 1-3-10 sequence. Max. full scale sensitivity 1 mv. Large 5" true log voltage scale, linear 12 db scale, generous overlap. High stability, high input impedance. Also useful as amplifier for small signals, or to monitor waveforms.

hp 400H PRECISION VOLTMETER—$325
Extreme accuracy as high as ±1% to 500 KC, ±2% to 1 MC, ±5% full range. Frequency coverage 10 cps to 4 MC. Large 5" meter with precision mirror scale. Voltage range 0.1 mv to 300 v; max. full scale sensitivity 1 mv. High 10 megohm input impedance minimizes circuit disturbances. Amplifier with 56 db feedback insures lasting stability. Reads direct in db or volts.

hp 400D WIDE RANGE VOLTMETER—$225
Highest quality, extremely versatile. Covers 10 cps to 4 MC. Highly sensitive, accurate to within ±2% to 1 MC. Measures 0.1 mv to 300 v; max. full scale sensitivity 1 mv. Reads direct in dbm. High 10 megohm input impedance virtually eliminates circuit loading. 56 db amplifier feedback insures high stability and freedom from change due to external conditions.

Data subject to change without notice. Prices f.o.b. factory

hp complete precision voltage measuring equipment

AMPHENOL *Quick-Crimp*

BNC CONNECTORS

CUT ASSEMBLY TIME *IN HALF!*

AMPHENOL's new *Quick-Crimp* Series BNC connectors* obsolete just about every other BNC now on the market. Here's why:

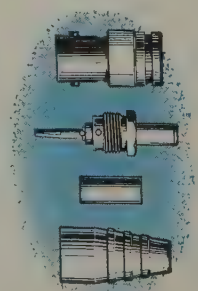
1 QUICK ASSEMBLY Only three basic parts (plus an optional boot) for you to assemble and crimp, as compared to as many as ten parts in a standard BNC! Assembly time is cut in half!

2 INCREASED RELIABILITY Critical assembly operations have been eliminated; inspection is easier, faster, reliable. Cable retention and strain relief is greatly improved. Connectors are weather-proof.

The *Quick-Crimp* family consists of 19 connectors: Plugs, Right Angle Plugs, Jacks, Bulkhead Jacks and Cable Terminations. *Quick-Crimps* mate with standard BNCs. Center contacts are gold-plated, have AMPHENOL's patented captivated contact** construction. Voltage rating is 500 V. peak. VSWR is low up to 10K mc.

*U.S. PATENT PENDING **U.S. PATENT 2,870,420

Body Assembly, Ferrule Clamp
Nut Assembly, Outer Ferrule and Boot
—Only Four Parts to Assemble!



AMPHENOL CONNECTOR DIVISION

AMPHENOL-BORG ELECTRONICS CORPORATION *Chicago 50, Illinois*

Professional Group Meetings

(Continued from page 114A)

Automatic Control/Military Electronics

Boston—February 9

A Discussion of the Problem of Safe Reentry of a Manned Satellite and a Description of the Control System Required to Accomplish This, H. Wexler.

Broadcasting

Florida-West Coast—April 8

"Application of Transistors to Audio and Wave Shaping Circuits," R. Hoffman, Electronic Communication Inc.

Communication Systems

San Francisco—January 27

"Digital Signaling and Control in Communications Systems," A. R. Ogilvie, Secode Corp.

Component Parts

Philadelphia—March 19

"Thermistor Seminar,"—Vendor-User Stds. Working Group Representatives of 8 Vendors, 9 Users and 6 Armed Services Groups.

"The Thermistor—Theory & Application," B. Schwartz, RCA—Central Eng. Services.

Los Angeles—March 9

"RCA Micromodule Program," J. Fort, RCA.

Electron Devices

Washington, D.C.—March 19

"Electron Beam Parametric Amplifiers," G. Wade, Stanford Univ.

Electron Devices/Microwave Theory and Techniques

Los Angeles—March 16

"Solid State Parametric Amplifier," R. D. Weglein, Hughes Aircraft Co.

Electronic Computers

Akron—February 18

"Behavior Models," A. J. Cacioppa, Goodyear Aircraft Corp.

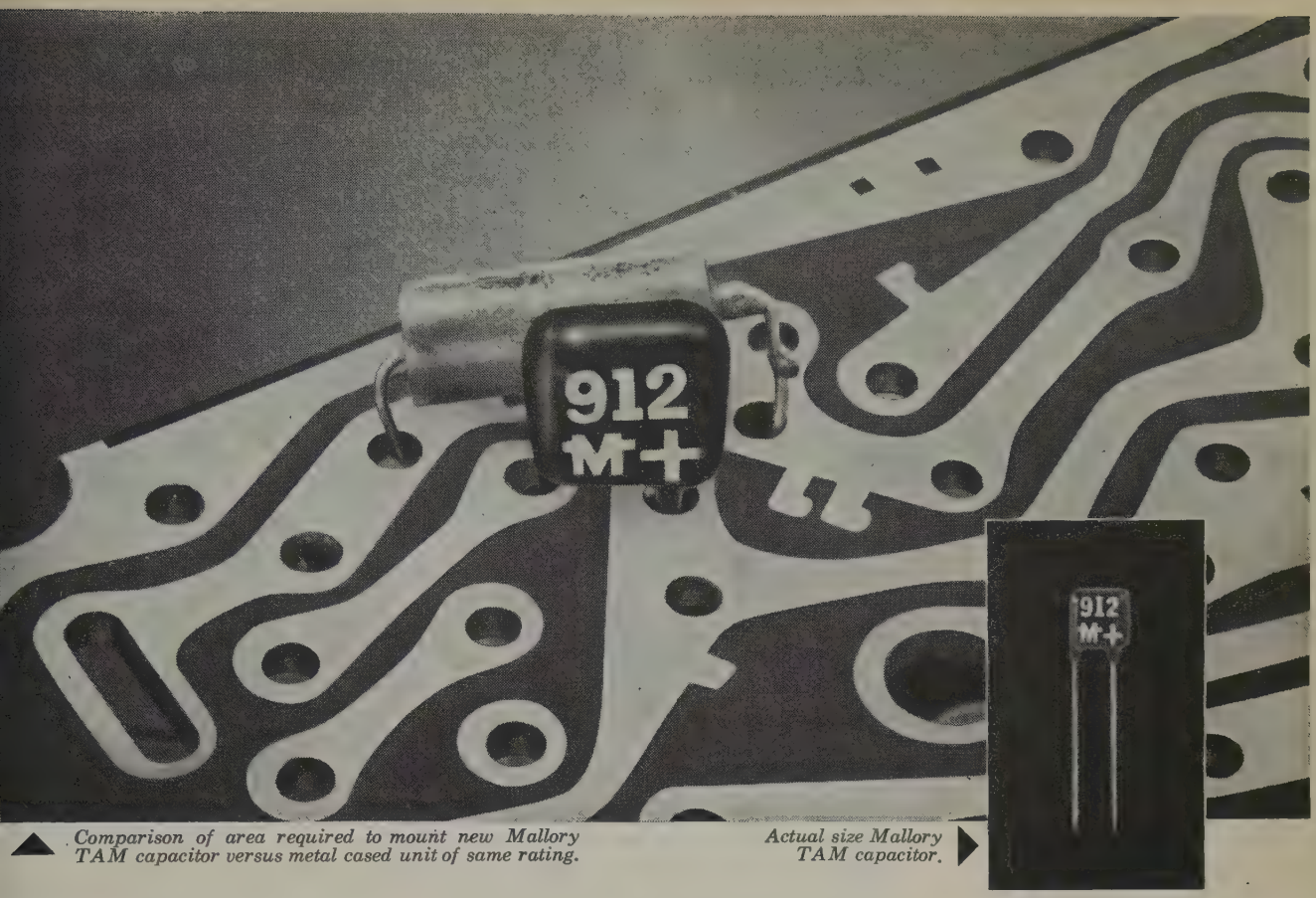
Binghamton—March 9

"Information Storage in Micro-Space," S. Newberry, Gen. Elec. Co.

Philadelphia—March 12

"Stock Predictions by Computers," Mr. See, Merrill Lynch, Pierce, Fenner and Smith.

(Continued on page 122A)



Comparison of area required to mount new Mallory TAM capacitor versus metal cased unit of same rating.

Actual size Mallory TAM capacitor.

NEW Encapsulated Tantalum Capacitor Saves Space, Weight and Cost

The first commercially available solid electrolyte tantalum capacitor *without* a metal case, the Type TAM is the latest in the wide line of Mallory tantalum capacitors. Its flat, rectangular design gives you new compactness and light weight especially useful in printed circuits . . . at a cost substantially below metal can types.

The TAM takes only about one-third the chassis space of its metal counterpart, and weighs about 30% less. It is fully insulated from the chassis and from adjoining components. Grid-spaced leads are dimensioned to EIA printed circuit standards; negative lead is rectangular for identification.

To protect the new TAM capacitor against moisture, Mallory engineers developed, and exhaustively tested, a new special coating compound. Overall size is $\frac{5}{16}$" square by .175" thick. Temperature range is −55°C to +85°C. Seven ratings are currently available: 56 mfd., 6 VDC; 39 and 33 mfd., 10 VDC; 22 mfd., 15 VDC; 15, 10 and 6.8 mfd., 25 VDC. Write today for complete data and prices, and for a consultation on your circuit application.

See Mallory for the most complete line of Tantalum Capacitors

Pioneer in tantalum capacitors, Mallory makes 15 different types:

HAT: microminiature size	XTL: 200°C rating
TAP: miniature, 100°C rating	XTH: 200°C, small diameter
TAP2: miniature, wide range of ratings	XTK: 175°C, smaller case
TAS: solid electrolyte	XTO: 200°C, shorter shape
TNT: miniature, axial leads	XTV: high capacity, 175°C
STNT: subminiature	M2: miniature, 150°C
XTM: miniature, 175°C rating	TAF: tantalum foil
	TAM: encapsulated

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MALLORY
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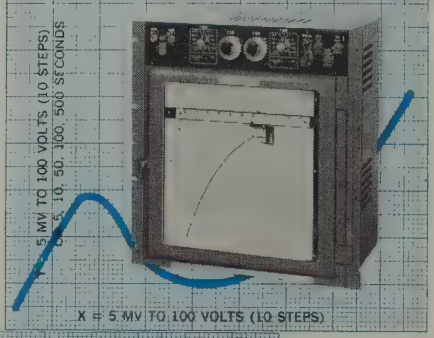
An accurate two-axis graphic recorder for automatically plotting any test data that can be reduced to electrical form. Built-in sweep circuit permits plotting dependent variable against time. With appropriate accessories will:

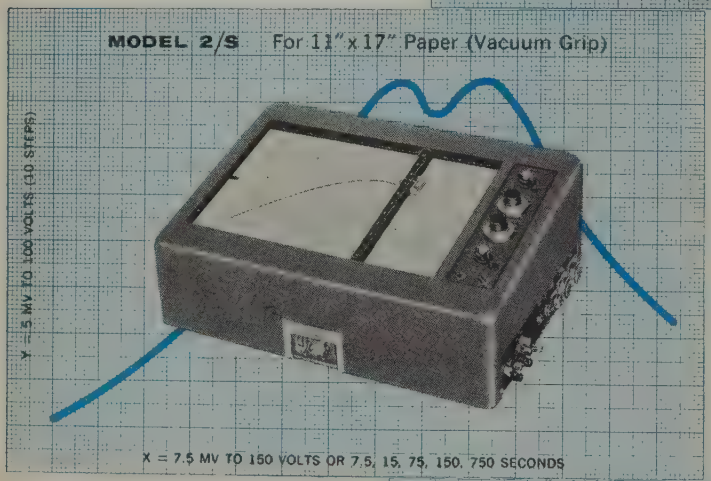
- ✶ Read out original electrical data from curves. (Curve Follower)
- ✶ Plot identified points from Keyboards, Tape, or Cards.
- ✶ Automatically produce Gain-Frequency records.

✶ *with* **TIME BASE**

MODEL 6/S
AUTOMATIC FRAME ADVANCE
10" x 10" Recording Area (Vacuum Grip)



MODEL 2/S For 11" x 17" Paper (Vacuum Grip)



Model 2/S
$1925

Model 3/S
$1300

Model 6/S
$2750

All models illustrated feature:

- ✶ Independent servo-actuated drives, isolated from ground, each axis.
- ✶ Continuous type range controls, plus accurately calibrated range steps.
- ✶ Zero set and one full scale of zero suppression for each axis.
- ✶ 200,000 ohms per volt to 2 meg-ohms input resistance, each axis.
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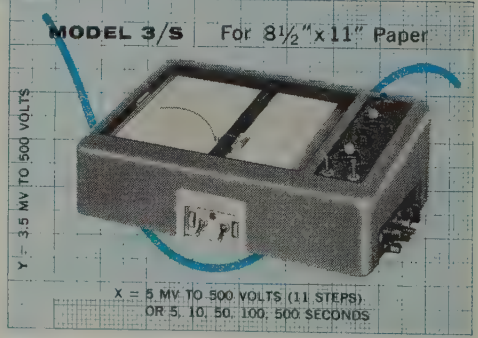
- ✶ Accuracy better than 0.25% of full scale; resetability within 0.1%.

MODEL 3/S For 8½"x11" Paper



All prices f. o. b. factory. Prices and specifications subject to change without notice.

Sales representatives in all principal areas.

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409 N. Fair Oaks Ave., Pasadena, California

how to see high impedance ac signals

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Features of the Model 102B are: decade gains from 0.1 to 1000, selectable bandwidths of 2 cps to 150 kc and 2 cps to 1.7 mc, and a 5-volt, 50-ohm output for scopes and recorders. Other features include:

- **input impedance** of 400 megohms, shunted by 3 $\mu\mu$f.
- **low noise level,** below 10 μv from 10 cps to 150 kc at maximum gain.
- **gain accuracy** of 1% at midband for all gain settings.
- **rise time** of 0.3 μ sec at highest gain.
- **two accessory** low capacitance probes available.
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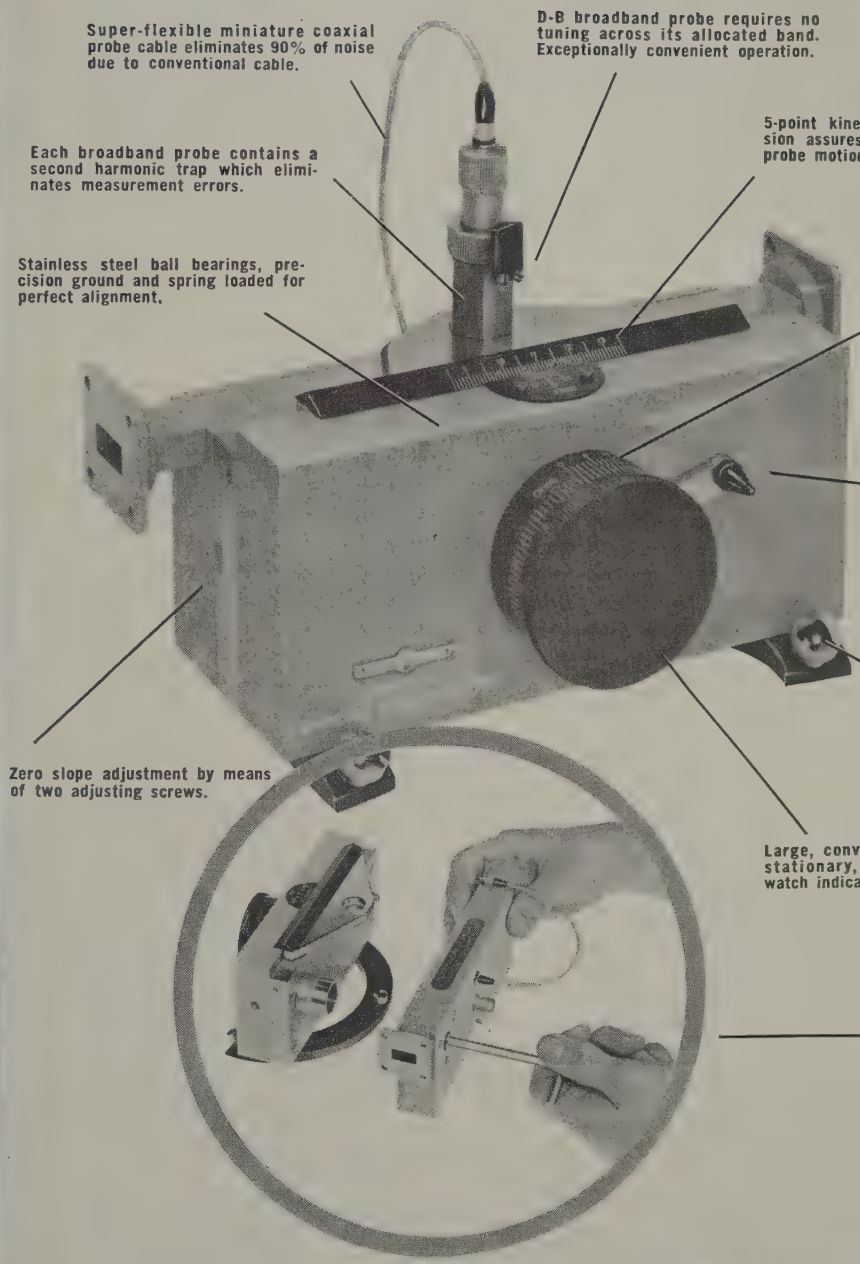

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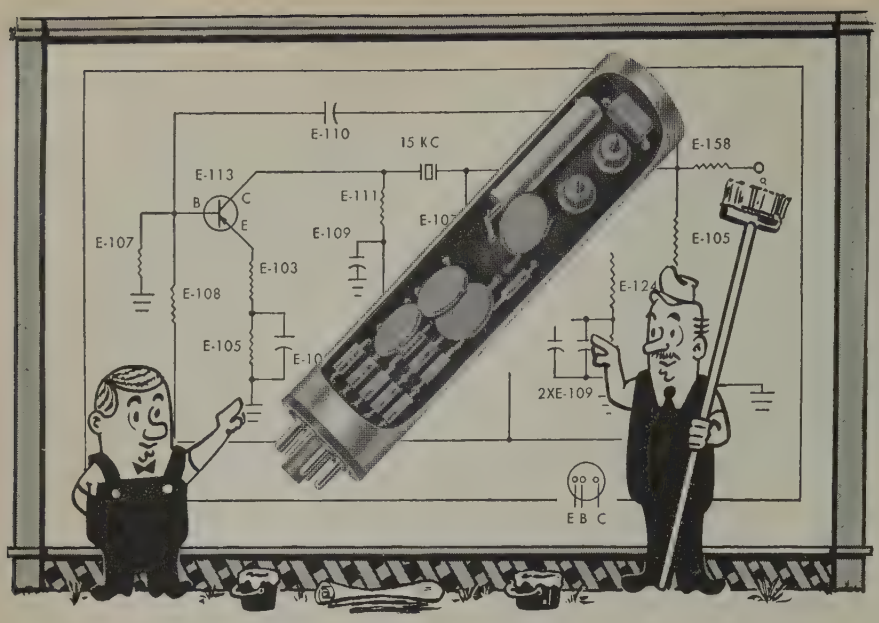

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New Reeves-Hoffman oscillators are transistorized for compactness and crystal controlled for unerring accuracy. Each oscillator is produced and tested with exacting care by skilled craftsmen using the most modern equipment and facilities available. Reeves-Hoffman will manufacture these units in volume to your specifications.

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Professional Group Meetings

(Continued from page 118A)

Philadelphia—April 9

"Logic Design of the RCA 501 System," J. G. Smith, RCA.

San Francisco—March 17

"The Use of Redundancy in Digital Computers," W. H. Kautz, Stanford Res. Inst.

Washington, D.C.—March 11

"Computer Components," R. H. Baker, M.I.T. Lincoln Lab.

Engineering Management

Boston—February 26

"Sylvania's Approach to Engineering Management Selection and Development," H. Reinhardt, Sylvania Elec. Prods.

Los Angeles—February 10

"Developing Engineering Managers," J. Pettit, Stanford Univ.

Rome-Utica—February 3

"Tracking and Telemetry Integration for Space Vehicles," C. I. Cummings, Jet Propulsion Lab.

Syracuse—March 5

"Engineering Management," R. W. Hodgers, Gen. Elec. Co.

Washington—April 13

"Armed Forces Management Ass'n—A New Assist to Defense," H. E. Sears, Exec. Dir. Armed Forces Management Ass'n.

Engineering Writing and Speech

Boston—Janaury 22

"How to Win Engineers and Influence Scientists," B. Dudley, M.I.T.

Los Angeles—January 21

"Military Contracts and Proposals," J. H. Rothrock, RCA.

Los Angeles—February 18

Business Meeting.

San Francisco—February 10

Organizational meeting; general discussion of functions and objectives; ad hoc committee appointed.

Information Theory

Boston—October 29

"Artificial Intelligence," M. Minsky, M.I.T.

Boston—December 3

"New Experimental Results in Coding," M. Horstein, M.I.T.

(Continued on page 136A)

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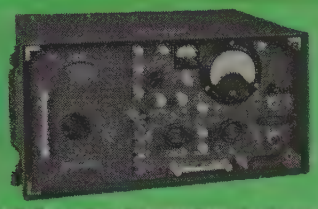

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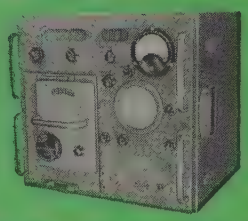
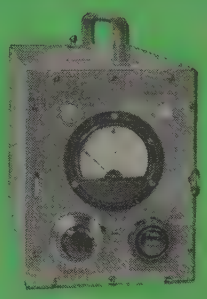
Use of five quick-change tuning heads avoids costly repetition of components common to all frequency ranges. Built-in impulse generator serves as calibrator. Carrier and peak reading VTVM. Fully regulated power supply.



NOISE AND FIELD INTENSITY METER

Companion unit to NF-105. Four interchangeable tuning heads. Excellent shielding effectiveness. Calibration by means of built-in impulse generator. Compact. Simple to operate.

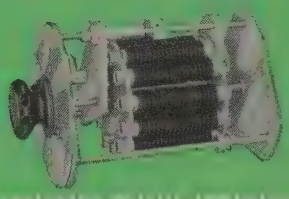


RADIATION POWER DENSITY METER

Personnel safety indicator. Average power from 1 mw/cm² to 1 w/cm². Complete with 3 pick-up probes. Portable. Self-contained.

AM MODULATION METER

Indicates modulation percentage of signal generators and transmitters. RF sensitivity 0.01 volts. Two plug-in tuning units.

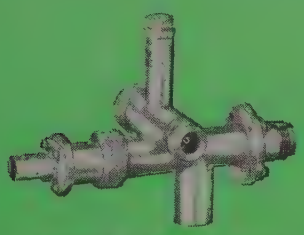


BROADBAND COAXIAL ATTENUATORS

Pads, 6 and 12 position step attenuators (manually and motor operated), attenuator panels. 1 watt to 4 watts. Also 50 watt power attenuators. Large range of values. Low VSWR, high accuracy. Long term stability. Conservative power ratings.

NOISE AND FIELD INTENSITY METER

Modified version of Model NF-105.

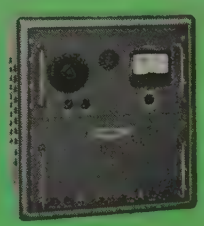


BROADBAND CRYSTAL MIXERS

Eight fixed tuned models. Low noise figure. Laboratory or production applications. Versatile.

BROADBAND POWER DIVIDERS

Five models permit lossless, accurate division of RF power. Many special versions available.



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Low distortion. Excellent regulation. Quick recovery. Wide frequency range.

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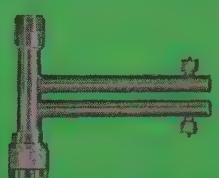
Generate high output level of impulse noise over wide frequency range. For receiver gain calibration, noise susceptibility investigations.



BROADBAND COAXIAL STUB TUNERS

Single, double and triple stub tuners of rugged construction. Locking nuts insure stable operation.

COAXIAL TERMINATIONS

Low VSWR throughout. Type "N" connector. Many special versions available.

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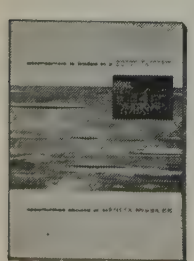

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Positions Wanted

By Armed Forces Veterans

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The IRE publishes free of charge notices of positions wanted by IRE members who are now in the Service or have received an honorable discharge. Such notices should not have more than five lines. They may be inserted only after a lapse of one month or more following a previous insertion and the maximum number of insertions is three per year. The IRE necessarily reserves the right to decline any announcement without assignment of reason.

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15 years experience, particularly strong in electro-mechanical field and analog computers. Also has done hydraulic, optical, and electronic development. Career interest in management and technical direction of R & D activities. Box 2000 W.

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Ph.D. MIT. 1953. Assignments in microwave heating, other electronic applications to biological and food problems, technical surveys, diversification studies, and information research. Registered professional engineer, inventor, teacher and author. Box 2011 W.

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Computer scientist with 17 years general electronics experience. Large experience in translation of Russian electronics literature. Will accept single-shot or steady outside translation work up to 75,000 words per month. Box 2012 W.

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Engineer with BS. degree wishes to relocate to small town or suburb on west coast. 10 years design and development experience including television, Airborne VHF communication and RF and AF transistor circuit design. Top 10% of graduation class. Now located with A-1 manufacturer in midwest. Box 2013 W.

(Continued on page 126A)

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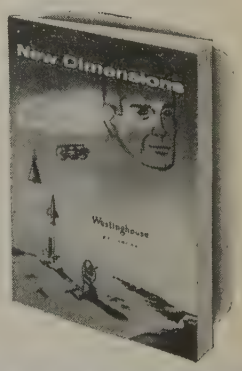

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Positions Wanted

By Armed Forces Veterans

(Continued from page 124A)

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BSEE., MSEE., MBA., PE. 12 years of microwave and television design, systems and administration experience. Presently Engineering Director. Seeking high level responsible position. Location secondary to opportunity. Box 2014 W.

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12 years intensive experience in program planning, budgeting and administration; product, market and media analysis; technical advertising, sales promotion and publicity copy; company-agency liaison, Government, industry, community and press relations. Licensed radio operator/mechanic with marketing background in electronic, nucleonic, aviation and allied industries. B.S.—Engineering Management, MBA.—Industrial Marketing, Ph.D. candidate—Advertising. Age 39. Desires company or agency affiliation with broader responsibilities leading to marketing management. Box 2016 W.

ELECTRONIC ASSISTANT

Married veteran; Associate of Applied Science, degree in Electrical Technology. 1st class Radio Telephone license, Signal Corps Communications school training. Seeks interesting and challenging position in sales or as a sales correspondent, as technician, as engineer assistant or as broadcast technician in communications or electronics industries. Northeast area preferred. Box 2017 W.

MANAGEMENT-ENGINEER

Broad background in operational requirements for military systems, particularly in airborne electronics. Also in organization and management. Desires challenging position of responsibility, preferably in mid-west. BS. (USMA), MS. in engineering electronics. Naval aviator. Age 38. Available July 1959. Box 2018 W.

PROFESSIONAL ENGINEER

Broad experience in management and engineering, seeks interesting, remunerative and challenging association. Reg. Washington D.C. prof. eng; BS. FCC licenses, etc. 14 years experience in broadcast, communications, FCC and management engineering. Senior Member, active on IRE technical committees; NTSC., etc. author 6 books, over 100 articles. Present contract expires shortly, do not wish to stay overseas. Prefer a southwest state, Washington, D.C. fine; well known in industry. Excellent references. Box 2023 W.

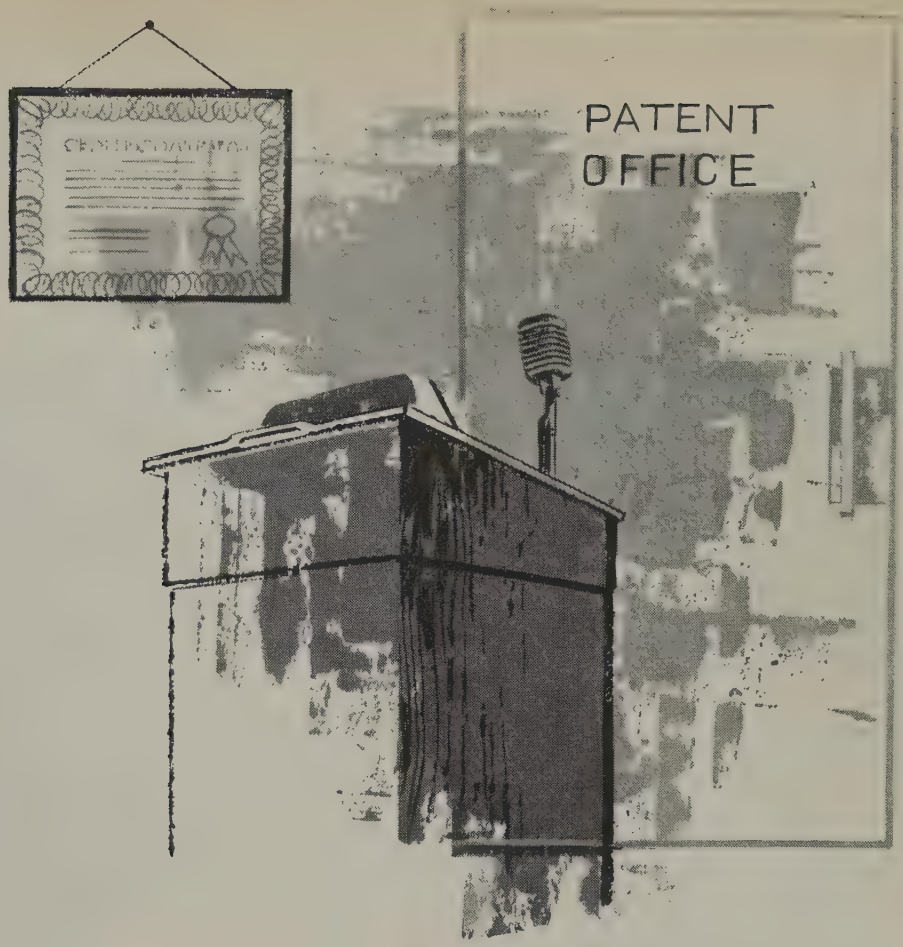
ELECTRONIC ENGINEER

BSEE. 1955; MSEE. 1957; Eta Kappa Nu, Tau Beta Pi, Phi Kappa Phi. 3 years experience on radar simulators, UHF aircraft radio and circuit development. At present Army Officer (Signal Corps), available July 1959. Prefer Phila. area but will relocate for outstanding opportunity. Box 2024 W.

PHYSICIST

34 years experience in communication laboratory, desires position in southwest U. S. BA., MA., Ph.D. Member American Physical Society, member IRE. Has worked in loudness studies, sound recording, network and filter design. Interested in statistical problems. Security clearance. Married. Box 2025 W.

(Continued on page 130A)



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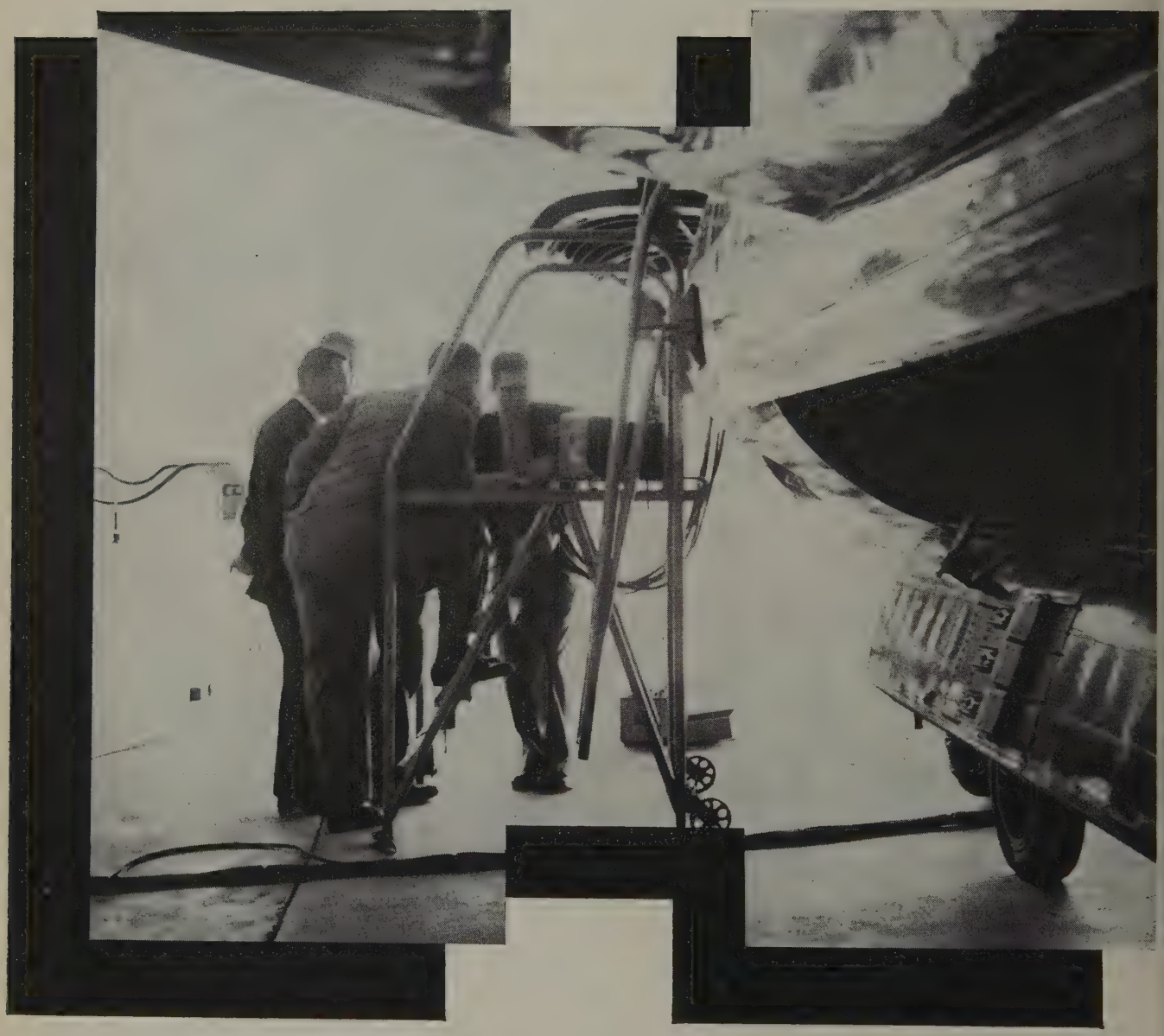
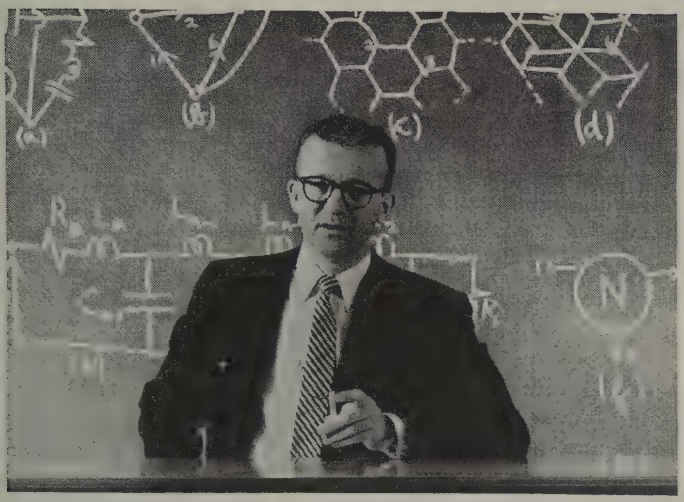


clear heads



NETWORK SYNTHESIS *is one of the many areas of study at Hughes Research and Development Laboratories. This work includes lumped and distributive parameter systems, both passive and active.*

TESTING THE TESTERS — *At Hughes Advanced Electronics Manufacturing Division, test equipment designed and built for Hughes Weapons Systems is often as sophisticated as the systems themselves!*

...and keeping them "thinking" clearly is the job of the Hughes Field Engineer. Invariably you'll find him in the company of top armed services and aircraft manufacturer's personnel. As in the photo at far left, his laboratory is in the field, evaluating a highly advanced Hughes Electronic Weapons System.

Drawing on a firm base of training in the total system, he judges and evaluates its performance. One of his key jobs is suggesting basic modifications. Simultaneously, he maintains close liaison with Hughes manufacturing groups to insure the highest standards of reliability.

The Hughes Field Engineer is typical of engineers and scientists throughout the Hughes organization. Here, the individual is given every opportunity to work out his ideas, to add measurably to his professional stature.

At Hughes Ground Systems Division, for example, engineers and scientists are now exploiting a major breakthrough — 3-D radar. This new development is acknowledged as the most significant progress step since radar itself was discovered.

At Hughes Products, advanced work is being done on a variety of automatic control systems, microwave tubes and new semiconductor devices.

Whatever your field of interest, you'll find Hughes diversity of advanced projects makes it the ideal place for you to grow... both professionally and personally.

Newly instituted programs at Hughes have created immediate openings for engineers experienced in the following areas:

Communications	Environmental Engineering
Industrial Systems	Logical Design
Electron Tubes	Radar Circuit Design
Field Engineering	Material & Component Eng.
Semiconductors	Systems Analysis
Test Equipment Eng.	Systems Management

Write in confidence, to Mr. John Case, Hughes General Offices, Bldg. 6-E6, Culver City, California.

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The West's leader in advanced ELECTRONICS

HUGHES

HUGHES AIRCRAFT COMPANY
Culver City, El Segundo, Fullerton and Los Angeles, California
Tucson, Arizona

ELECTRONIC ENGINEERS

STAVID seeks energetic engineers and scientists who aspire to promote their professional careers with a growing organization. Challenging positions for experienced graduate engineers are immediately available in new and exciting military electronic programs. All inquiries will receive prompt attention and will be held in strict confidence.

DEVELOPMENT ENGINEERING

PLAINFIELD, N.J.

SENIOR SCIENTIST

High level position requiring extensive experience in systems engineering related to radar, countermeasures or fire control systems. Airborne or shipboard equipment background desirable. Should be capable of generating new and proprietary ideas using advanced design principles and techniques, and possess proficiency in preparing proposals for formal presentations (oral and written).

RADAR SYSTEMS DESIGN ENGINEERS

Experience in design, development and analysis of airborne systems including fire control, reconnaissance, navigation, bombing, etc. Sub-system experience in radar and computers desirable.

DESIGN ENGINEERS

—TRANSISTOR APPLICATIONS
Capable of designing IF strips, frequency multipliers and oscillators, video detectors, and switching circuitry.

—PULSE MODULATORS & TRANSMITTERS
Capable of designing high-powered circuits and distributed RF amplifiers.

ELECTRONIC PACKAGING ENGINEERS

Electronic packaging experience with interest in stress analysis and thermodynamics desirable. Knowledge of design requirements for shock and vibration protection.

ANTENNA DESIGN ENGINEERS

Experience in high and low power search and fire control radar antennas of parabolic, horn, slot array, polyrod and pillbox types. Experience in flush antennas, slot feeds, ferrite controlled monopulse feeds and arrays highly desirable.

FIELD ENGINEERING

CIRCUIT DESIGN ENGINEERS

3 to 5 years exp in design, modification and testing of pulse & gating circuits, video displays, digital circuitry, digital storage, digital communications, tape recording & process equipment. Project concerns research, installation, testing, development & modification of experimental data process equipment. (Location: Boston, Mass.)

POWER COMPONENT SPECIALIST

8-10 years' experience in design of synchros, resolvers, servo motors, gyros and tachometer generators. Must be familiar with techniques used in manufacturing, testing and inspection of these components. Quality control and standardization experience desirable. EE degree required. (Location: Plainfield, N.J.)

DESIGN AND MODEL TESTING OF:

—Low-frequency communication and filter networks.

—Transmission transformers.

—Magnetic amplifier, voltage stabilizers and packaged transistor circuitry.

—Passive circuit components, including tantalum electrolytic capacitors and lacquer film capacitors (BS degree in physical chemistry or electro-chemistry).

(LOCATION: NORTH CAROLINA)

TECHNICAL WRITERS

Experienced writing instruction books to government specifications. Should be capable of carrying projects with minimum supervision. Substantial electronics background desirable. Physics or math degree preferred. Journalism degree acceptable if accompanied by training obtained during military service in an extended course in radar or electronics.

LOCAL INTERVIEWS ARRANGED IN YOUR AREA

Send Resume To:
J. R. Clovis,
Personnel Dept. "M"

STAVID
Engineering, Inc.
U. S. HIGHWAY 22
PLAINFIELD, NEW JERSEY
Imaginative Electronics...

Positions Wanted

By Armed Forces Veterans

(Continued from page 126A)

MANAGER-ENGINEER

6 years diversified experience as corporate manager and engineering director with additional experience encompassing corporate organization, sales, advertising, publicity, public speaking and technical writing. 17 years electronics background in communications, instrumentation, radio and TV development and design. Registered professional engineer. BSEE. Purdue University; Senior Member IRE; Age 37; married; 3 children. Box 2026 W.

EDUCATOR-EDITOR-ENGINEER

BA., BSEE., MA., MS; Major USAF Res. 15 years experience training, writing and supervising engineering projects. Knowledge Spanish, Portuguese, Italian, French, German, Russian. International relations and Military Intelligence. Desires responsible position overseas. Box 2027 W.

Positions Open

The following positions of interest to IRE members have been reported as open. Apply in writing, addressing reply to company mentioned or to Box No. ....

The Institute reserves the right to refuse any announcement without giving a reason for the refusal.

Proceedings of the IRE
1 East 79th St., New York 21, N.Y.

INSTRUCTORS

For those interested in teaching fundamental electrical and electronic subjects. Openings for fall semester beginning September 1959. Salary depends on qualifications. New building and equipment. Opportunity for advancement and further study. 9 month academic year. Part-time evening session work available. Health insurance and pension plan. Send complete resume to Professor L. I. Kiskow, Dept. Head, Electrical Technology, Staten Island Community College, 50 Bay St., Staten Island 1, N. Y.

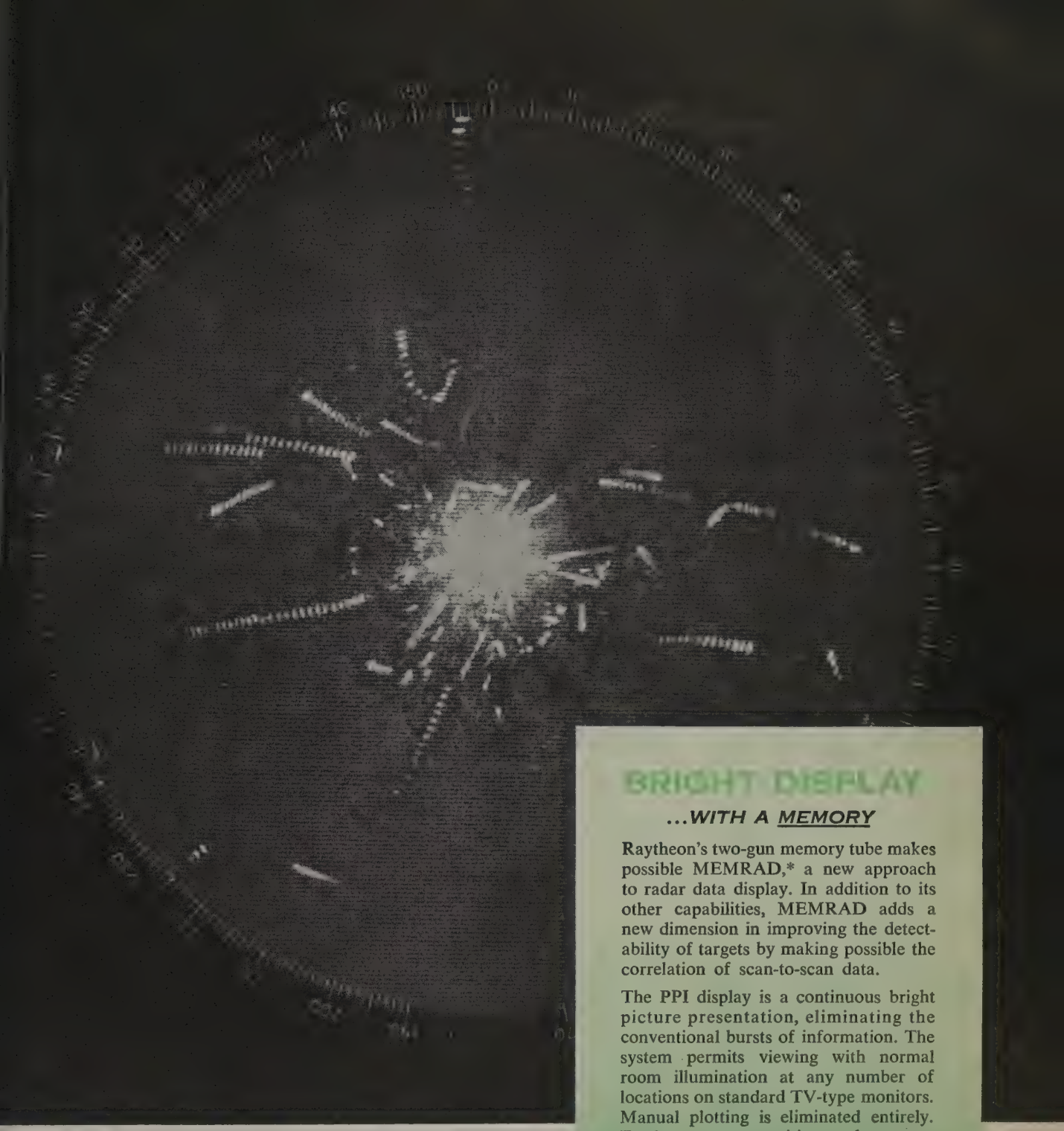
TECHNICAL WRITERS

Teleregister designs and develops some of the world's largest data processing systems. We have immediate openings for both Junior and Senior technical writers to prepare a variety of brochures and manuals. Moving expenses paid, many company benefits. If you would like to join a growing company, send your resume to Paul H. Callender, The Teleregister Corp., 445 Fairfield Ave., Stamford, Conn.

TEACHING-RESEARCH

Full year appointments available. Research needs presently in field of electronic countermeasures with other fields possible. Teaching in new undergraduate program with strong engi-

(Continued on page 132A)



BRIGHT DISPLAY

...WITH A MEMORY

Raytheon's two-gun memory tube makes possible MEMRAD,* a new approach to radar data display. In addition to its other capabilities, MEMRAD adds a new dimension in improving the detectability of targets by making possible the correlation of scan-to-scan data.

The PPI display is a continuous bright picture presentation, eliminating the conventional bursts of information. The system permits viewing with normal room illumination at any number of locations on standard TV-type monitors. Manual plotting is eliminated entirely. Furthermore, recognition and comprehension of target trails are made possible by presenting the recent history of target position. MEMRAD allows an immediate assessment of target velocity and maneuver, permitting discrimination between jet and conventional aircraft.

**Raytheon Trademark*

PROFESSIONAL ASSOCIATION WITH A FUTURE

Raytheon has excellent openings for qualified engineers and physical scientists with BS or advanced degrees interested in systems, development, design or manufacturing engineering of complex electronic equipments. Please write Donald H. Sweet, Government Equipment Division, Raytheon Company, 624 Worcester Road, Framingham, Massachusetts.

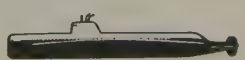
Engineering Laboratories: *Wayland, Maynard, Sudbury, Mass.; Santa Barbara, Calif.*
Manufacturing Facilities: *North Dighton, Waltham, Mass.*

RAYTHEON

Excellence in Electronics

GOVERNMENT EQUIPMENT DIVISION

LAND



SEA

AEROSPACE

■ ENGINEERS—SCIENTISTS ■

Work on

TOTAL SOLUTIONS

to Major Defense Problems

at General Electric's Defense Systems Department

You'll find greater opportunities in Systems Engineering in an organization whose charter has a breadth and scope seldom met in industry:

...to find total solutions to specific large scale defense problems requiring the integration of diverse fields of knowledge and equipments. These problems will be of sufficient magnitude and duration to justify the allocation by General Electric of considerable numbers of highly qualified scientists and engineers to contribute *systems program management* and *systems engineering support*—on programs such as:

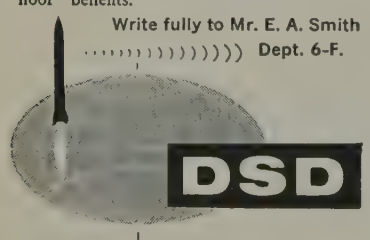
ATLAS • DYNA-SOAR • SENTRY
...and other highly classified systems which cannot be listed here.

Immediate Opportunities for:

Systems Program Engineers
Systems Management Engineers
Guidance Equation Engineers
Data Processing Engineers
Electronic Systems Management Engrs.
Operation Analysts
Systems Logistics Engineers
Engineering Psychologists

Forward your confidential resume at an early date. Whereas growth potential here is evident—both for DSD and the engineers who join us—the positions filled during these early months will carry significant "ground-floor" benefits.

Write fully to Mr. E. A. Smith
Dept. 6-F.



DEFENSE SYSTEMS DEPARTMENT
A Department of the Defense Electronics Division

GENERAL ELECTRIC

300 South Geddes Street
Syracuse, New York

Positions Open

(Continued on page 134A)

neering science emphasis and E.E. graduate (M.S.) program. M.S. or Ph.D. required. 9 month salary range presently $5000-$9000. Arrangements can be made for combined teaching-research or for full research and teaching alternate semesters or years. Apply A. T. Murphy, Head, Dept. of E.E., University of Wichita, Wichita, Kansas.

TEACHING-ELECTRICAL ENGINEERING

An unusual opportunity exists for a recent graduate with MS. or Ph.D. Stimulating teaching assignments in a modern curriculum offer a unique combination of desirable professional experience. Salary range for 9 months $5000-$7000. Attractive full year contract available. Location is in the midwest at a medium size university. Send complete resume to Box 1092.

TECHNICAL RESEARCH

Technical gentleman with knowledge of research market to join group of scientists as stockholder and/or associate. Duties: Contact Government and industry research facilities regarding research proposals. Manhattan Physical Research Group, Inc. 556 West 191 St., New York 40, N.Y.

ELECTRICAL ENGINEERING PROFESSORS

Fast growing engineering school needs 3 electronic-electrical engineers able to teach circuits and electronics, with a speciality in communications, industrial electronics or computers. MS. degree plus industrial experience is the minimum requirement; a Ph.D. is desirable. Salary and rank depends on experience. The department has just moved into a new building and needs aggressive men who wish to develop curricula and laboratories. Apply: A. D. Graves, Dean, Los Angeles State College, Los Angeles 32, Calif.

TECHNICAL WRITERS

Burroughs Corp., Military Field Service Div. is expanding long term Atlas & Sage program in data processing, creating growth positions for technical writers with experience writing to military specifications on electronic equipment. Must have a good background in electronic theory. Qualified men will work in our modern facility located in an attractive Philadelphia suburb. Send resume to Mr. A. J. Bellace, Employment Supervisor, Dept. R-789, Burroughs Corp., Military Field Service Div., Burroughs Dr., Radnor, Pa.

SALES MANAGER

Electronic Instruments, Commercial Products Dept. of long established progressive engineering and manufacturing organization located on Long Island, N.Y. Must have engineering education with substantial successful sales management experience in electronic test and control instruments. Dept. operates through manufacturing representatives selling to prime contractors, government agencies, industrial organizations, and educational institutions. State experience, education and salary expected. Box 1093.

(Continued from page 130A)

ENGINEERS

RESEARCH — DESIGN — DEVELOPMENT

FOR CREATIVE ASSIGNMENTS WITH ADVANCED DEVELOPMENT GROUPS

Challenging tasks, long term employment, interesting programs

"Let's deal with specifics." Assignments at Daystrom require the performance of original work involving studies, design, and development of systems typical of those listed below.

NUCLEAR INSTRUMENTATION
Reactor control systems for atomic powered vessels and aircraft; Reactor protection and alarm systems.

AIRCRAFT AND MISSILE ELECTRONICS
Nose Cone checkout systems; Bombing and Navigational subsystems tester.

DIGITAL COMPUTERS
Solid State Display Generators; 20,000 word (67 bits per word) solid state memory system; Transistorized tactical data communications systems; Data collection and reduction system.

COMMUNICATIONS and TELEMETERING
Frequency synthesizers; Single sideband transmitters; Digital data translator; High stability receivers; Automatic direction finder; SSB telemetering system.

TRAINERS and SIMULATORS
Large tactical training system. 30 combat information center positions; Multiple target simulator for Monopulse Radar system; Pulse doppler radar simulator.

RADAR SYSTEMS
High performance search radar; Missile tracking and guidance radar; Monitoring beacons, Doppler navigator; Low level radar altimeter; Countermeasures systems.

Can you make a major contribution, are you interested in challenging problems rather than routine tasks? If so, we are interested in you. Work with others of equal ability and interests in an atmosphere stimulating to your professional growth.

For interview consideration, send complete resume in strict confidence to:

MR. JOHN E. THOMAS, Director of Research & Development

DAYSTROM INSTRUMENT
Division of Daystrom Incorporated **Archbald, Penna.**

THERE IS ROOM FOR YOU IN CROSLEY'S INFRARED SYSTEMS

One of the largest and fastest growing Infrared Systems departments in the country has Supervisory and Staff positions available for engineers and physicists.

Areas of interest include long range programs to significantly advance the state-of-the-art in:

Airborne Defensive Systems
Airborne Early Warning
AICBM Detection
Reconnaissance and Surveillance
Tracking and Track-While-Scan Systems
Passive Ranging
Anti-submarine Warfare

MR. JAMES T. DALE
Director — Scientific and Technical Personnel

Avco/Crosley

1329-O ARLINGTON STREET, CINCINNATI 25, OHIO

Professional Teamwork

In the fields of reconnaissance and surveillance the effective utilization of infrared requires the concentrated effort of both scientists and engineers.

At AVCO/Crosley a number of exciting developments are underway to extend the state-of-the art in practical applications of basic Infrared technology. Current fields of interest include reconnaissance systems, tracking devices, and ranging equipment. Illustrated above is one type of Infrared Track and Ranging Unit developed at Crosley.

AVCO/Crosley engineers are answering the problem of space conquest through the design of systems which include, among other devices, new concepts of infrared detection equipment.

professional opportunities

We offer an academic environment in mid-Manhattan of superior technical standards and high professional calibre. The work involves development of systems concepts (particularly weapons systems) under prime Government contracts. Opportunities for rapid and orderly growth are exceptional.

Our associates already have distinguished records in these fields:

Electronic Countermeasures; Air Defense Systems; Air Traffic Control; Advanced Nuclear Weapons Applications; Nuclear Physics; Digital Data Processing; Project Program Analysis

Your advanced degree in physics, electronic engineering or mathematics should be backed by demonstrated technical achievement . . . a thorough understanding of the laws of cause and effect, and sound application of scientific method.

Excellent Salaries ***Tuition Plan*** ***Three Weeks Vacation***

Inquiries are invited from qualified scientists.

G. C. DEWEY & CO., INC., 202 East 44 St., New York, N.Y.

ENGINEERS

Newport Beach, Southern California . . . Holds the Key to Your Future!

FORD MOTOR COMPANY'S young and rapidly expanding subsidiary, **Aeronutronic Systems,** Inc., is now offering outstanding opportunities for an excting and highly rewarding career to Computer Engineers capable of making significant contributions to advanced computer technology.

AERONUTRONIC—a dynamic new name in science and research—is moving into the future fast. The first phases of a new Research Center are nearing completion at Newport Beach, where California living can be enjoyed at its finest. You'll work in an intellectual atmosphere—in a community away from congestion, yet close to most of Southern California's cultural and educational centers.

These positions are now open:

- Systems Engineers
- Magnetic Memory Engineers
- Communications Engineers
- Digital Computer Programmers
- Transistorized Circuit Engineers
- Logical Designers
- Circuit Engineers
- Mechanical Engineers
- Optical Engineers

Qualified applicants are invited to send resumes or inquiries to Mr. L. R. Staple, Aeronutronic Systems, Inc., Box NR 486, Newport Beach, California.

COMPUTER DIVISION

AERONUTRONIC

a subsidiary of FORD MOTOR COMPANY

NEWPORT BEACH · GLENDALE · SANTA ANA · MAYWOOD, CALIF.

Positions Open

(Continued from page 132A)

ELECTRICAL ENGINEERING DEPARTMENT HEAD

Electrical Engineering Department head for fast-growing school needed Sept. 1959. Must have experience in teaching and research and ability to take charge of graduate program primarily for the aircraft industry. Contact E. W. Kimbark, Dean, School of Engineering, Seattle University, Seattle 22, Washington.

ELECTRONIC ENGINEERING

Kentron Hawaii Ltd., 1140 Waimanu St., Honolulu, Hawaii, has openings for graduate electronic engineers with at least 3 years experience in the operation and maintenance of military electronic equipment. Requirement also exists for communications specialists holding FCC licenses. Please write to Mr. R. D. Waterman at Kentron.

ELECTRICAL ENGINEERS

Electrical engineers experienced in transistorized circuitry, DC power supplies, magnetic amplifiers, and electronic test equipment, research and development, and design. Excellent opportunities and pay. Write Perkin Engineering Corp., 345 Kansas St., El Segundo, Calif.

(Continued on page 136A)

Transistor Engineer Wanted, To Head Laboratory, Italy

olivetti

Olivetti (Italy) has established a subsidiary in Milan for the production of silicon and germanium transistors and diodes.
It is now looking for the right person to head the existing development laboratory.
These are the requirements: (1) At least 5 years experience in transistor development
(2) Degree of Master of Science in Physics
(3) Willingness to move to Italy and learn Italian.
It would be desirable if you were familiar with present applications and future potentialities of transistors and diodes, in order to contribute actively to the general policy of the new firm.
Salary will be commensurate with experience and ability. Transportation and moving expenses will be paid.
Written replies will be sent to all applicants.
Chosen candidates will be invited for a personal interview in New York City, expenses paid.
Please write, enclosing detailed resume, to Project

T. D. L., Olivetti, Ivrea, Italy.

CAN YOU HANDLE THIS ASSIGNMENT FOR A PRINCIPAL ENGINEER?

For a specified spacial arrangement of transmitting and receiving elements in a radiation field, including signal, noise and reverberation:

1) Determine effectiveness of existing receiving systems in extracting signal from background

2) Design and analyse the effectiveness of new and improved receiving systems, using the most suitable optimum filtering techniques

3) Investigate use of broad band and coded transmissions, in conjunction with special receiving systems, as a means for improving signal detectability.

This application is one phase in the development of advanced detection systems for Anti-Submarine Warfare.

An MSEE degree in Physics or Mathematics with advanced training in information theory or engineering statistics and noise theory is desired. Experience should include:

1) Analysis and development of filtering techniques for extraction of coherent signals from noise

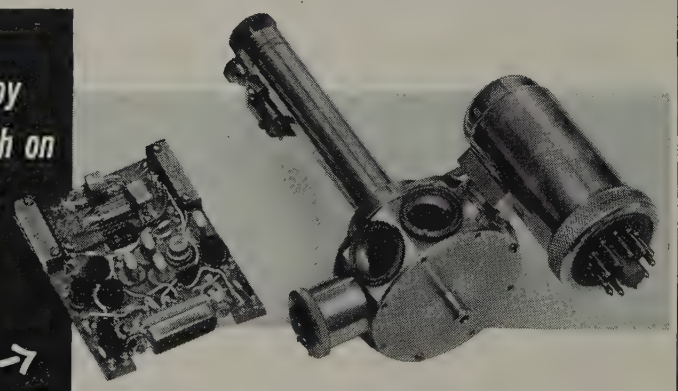
2) Analysis and development of digital techniques for receiving, storing, analyzing, and comparing electrical signals and noise.

Bendix-Pacific
DIVISION OF BENDIX AVIATION CORPORATION
NORTH HOLLYWOOD CALIFORNIA

Please send complete resume to W. C. Walker, Engineering Employment Manager.

Would you enjoy leading research on photoelectronic developments such as this?

Come and talk with us.

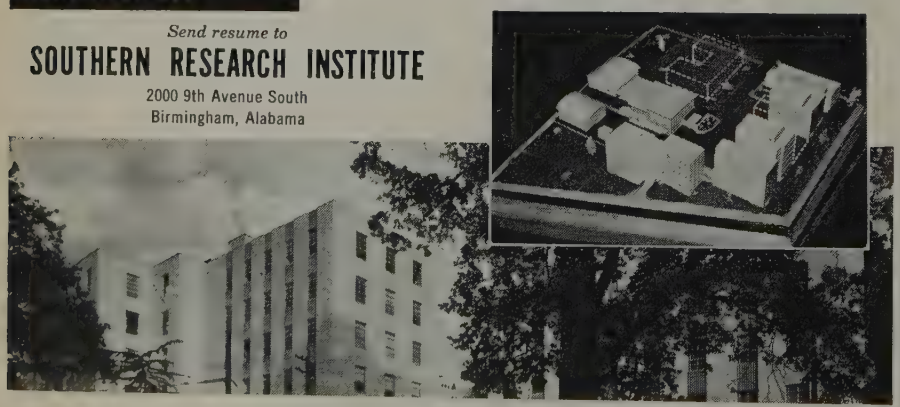


MR. SENIOR ELECTRONICS ENGINEER: We need you to lead research and development in this challenging field. Unusual opportunity—excellent personnel and surroundings —equable climate, good year-round living conditions.

Send resume to

SOUTHERN RESEARCH INSTITUTE

2000 9th Avenue South
Birmingham, Alabama



Positions Open

(Continued from page 134A)

ASSISTANT & ASSOCIATE PROFESSOR

Dept. of E.E. at State College has openings for Assistant and Associate Professors. Must have MS. or Ph.D. Progressive department needs men interested in advance circuitry or communications or computers. Teach undergraduate or graduate courses and conduct research if so inclined. Starts Sept. 1959. Salary dependent on qualifications. Friendly city of 50,000 people with excellent year round climate. Write Chairman, Dept. of E.E., North Dakota State College, Fargo, North Dakota.

ELECTRONIC INSTRUMENTS SALES ENGINEER

Graduate E.E. with 2-5 years engineering experience and desire for technical sales, or graduate E.E. currently active in engineering sales. For field engineering position in metropolitan New York area. Compensation, guaranteed base salary plus bonus. Interesting opportunity. Apply by letter only. Include resume. RMC Associates, 236 East 75 St., New York, N.Y.

PROJECT ENGINEER

Project Engineer to supervise complete projects in design and development of automatically sequencing, self checking test equipment used to evaluate complex airborne guidance systems and components. E.E. Plus 5-7 years experience. Apply Kearfott Co., Inc., 1500 Maine Ave., Clifton, New Jersey, Att: C. J. Weinpel.

ENGINEERS

Teaching Faculty is needed by Electrical Dept. of one of New York State's expanding community colleges. Salary range $5450.00 and up for B.S., $7190.00 and up for M.S. Completely new campus is under construction and will be completed in 1960. Apply to W. R. Pulhamus, Head, Electrical Dept., Mohawk Valley Technical Institute, Utica, N.Y.

PHYSICIST

Manager, Advanced Development Vacuum Products Group ,for Varian Associates. A rapidly expanding electronics firm located on San Francisco Peninsula. MS. in physics or equivalent. Minimum 5 years experience in pure or applied physics in a research or development organization. Experience need not be in field of vacuum physics as such. Challenging opportunity for man interested in entering rapidly expanding vacuum field. Excellent employee benefits including free Life, Hospital, Medical & Surgical Insurance, participation in Co. Stock Purchase Plan, Incentive Profit-Sharing & Retirement Plan. Send resume to J. A. Kallgren, Employment Mgr. Varian Assoc., 611 Hansen Way, Palo Alto 27, Calif.

Professional Group Meetings

(Continued from page 122A)

Boston—January 27

"Pandemonium—An Approach to Artificial Intelligence," O. G. Selfridge, M.I.T. Lincoln Lab.

(Continued on page 138A)

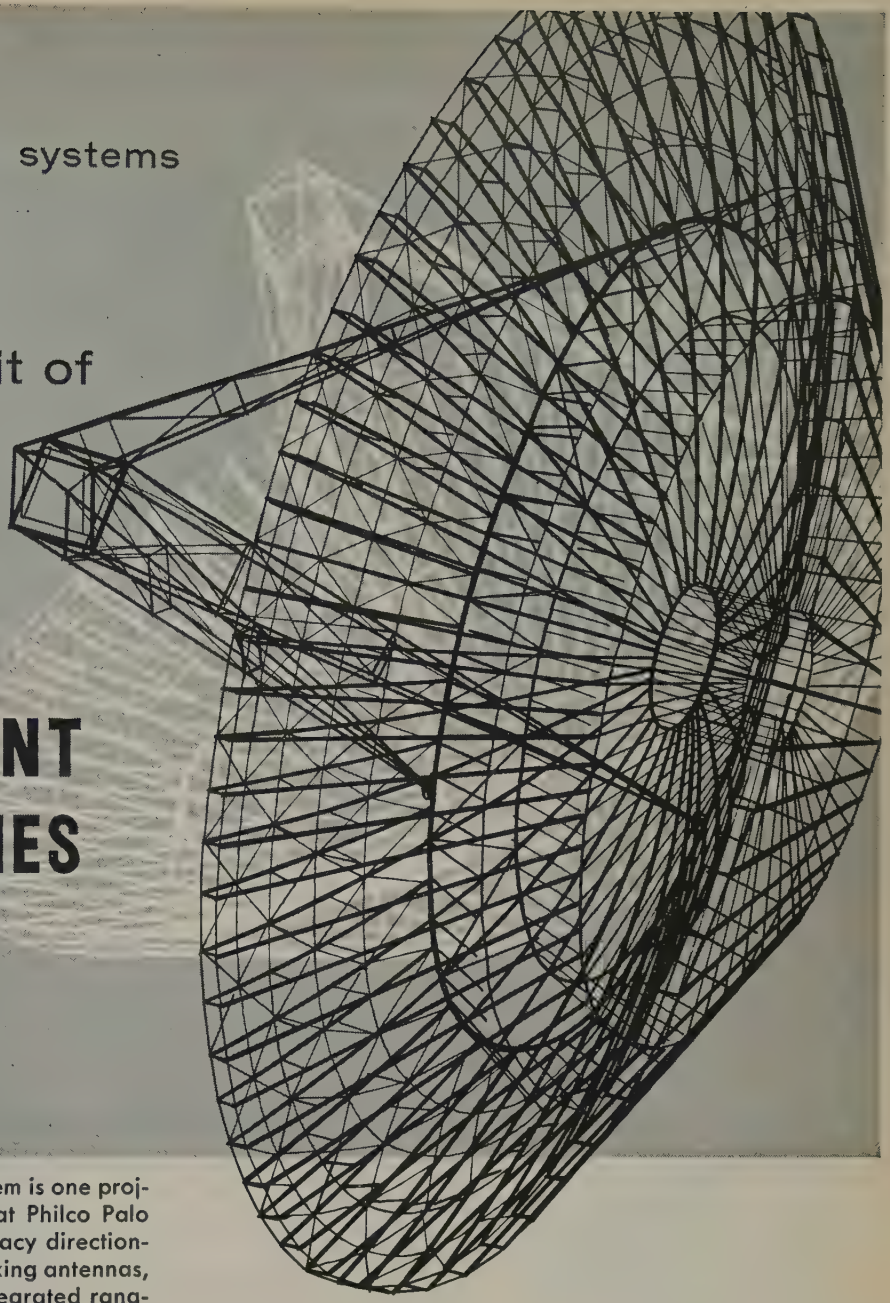
complete tracking systems

a basic pursuit of

PHILCO

WESTERN DEVELOPMENT LABORATORIES

PALO ALTO



An all-new, complete Space Tracking System is one project now under design and construction at Philco Palo Alto. The project encompasses high-accuracy direction-finding antennas, large passive slave-tracking antennas, high power transmitting antennas and integrated ranging equipment.

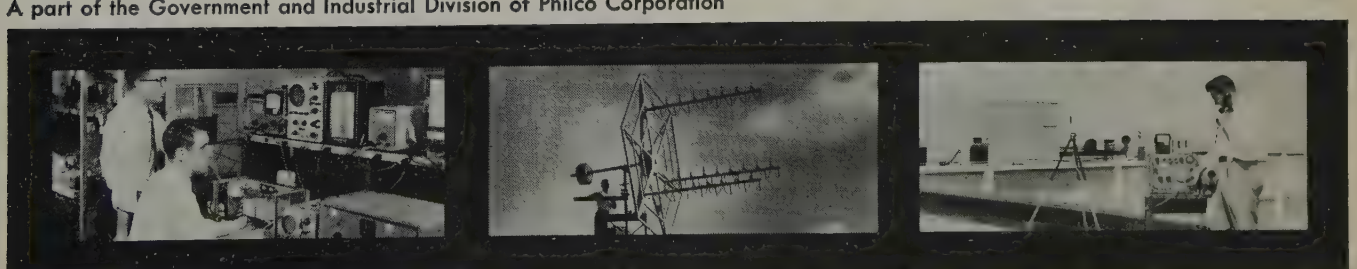
Pioneering in the precision tracking field, Philco Palo Alto needs alert, creative, enthusiastic Engineers and scientists of all levels who are qualified in structural, RF and servo design.

Your confidential inquiry is invited; please write H. C. Horsley, Dept. R

PHILCO WESTERN DEVELOPMENT LABORATORIES

3875 Fabian Way, Palo Alto, California
A part of the Government and Industrial Division of Philco Corporation

5510



Measuring phase stability vs. temperature during prototype equipment development

Developmental helical antenna, part of sophisticated new direction finder system

Pattern measurements—vital to development on microwave dish antenna

ELECTRONIC SYSTEMS ENGINEERS

Work on America's most advanced weapon systems

At North American Aviation work on such top-level projects as the B-70 and F-108 weapon systems and the X-15 manned space aircraft has created unique careers with a tremendous engineering potential. Openings exist for

Top-Level Systems Engineers interested in performing applied research for the laboratory evaluation of such complex electronic systems as fire control, bombing systems, mission and traffic control systems, air data, and automatic flight control. Evaluation consists of the integration of related electronic systems and related interference problems.

Other top-level positions are available in radome development, antenna development, and infra-red.

Minimum requirements are actual experience plus B.S., or advanced degree in E.E. and Physics.

For more information please write to: Mr. B. F. Stevenson, Engineering Personnel, North American Aviation, Inc., Los Angeles 45, California.

THE LOS ANGELES DIVISION OF

NORTH AMERICAN AVIATION, INC.

Professional Group Meetings

(Continued from page 136A)

Medical Electronics

Houston—March 10

"Description and Demonstration of Physiology Department Laboratories," L. Geddes, Baylor Univ. of Medicine.

Los Angeles—January 29

"Medical Electronics in Neuropsychiatry," J. C. Borel, M.D., Camarillo State Hospital.

"Highlights of the 1958 Conference on Electrical Techniques in Medicine and Biology," M. Biedeback, USC Dept. of Eng. and Dept. of Radiology.

Los Angeles—October 30

"Medical Electronics, Past, Present, and Future," J. P. Sampson, M.D.

Philadelphia—February 25

"Ultrasound in Medical Diagnosis," J. M. Reid, Moore School of Elec. Eng., Univ. of Pa.

Washington, D.C.—April 2

"The Aerosoloscope and Instrument for Measuring the Size Distribution of Aerosols," N. Alexander, Chem Warfare Sec. U. S. Army.

Microwave Theory and Techniques

Baltimore—March 18

"Ferrite Phase Shifters," C. M. Johnson, Electronic Communications, Inc.

Boston—March 18

"Problems in Noise Measurements on Masers and Parametric Amplifiers," H. A. Haus, M.I.T. Res. Lab. of Electronics.

Chicago—October 29

"Tour of Microwave Plant Facilities and Demonstrations," A. Kowitz, Motorola, Inc.

Chicago—November 14

"Recent Advances in Microwave Ferrites," Tore N. Anderson, Airtron Div. of Litton Industries.

Chicago—December 12

"Discussion of the 'Mavar'," (General Paper), Dr. C. L. Hogan, Motorola, Inc.

"Discussion of the 'Maser'," Dr. C. L. Hogan, Motorola, Inc.

Los Angeles—February 12

"Present Wage and Salary Pattern in the Electronics and Associated Industries," J. Given, Lockheed Aircraft Co.

"Reciprocal Ferrite Phase Shifters and their Application to Electronically Scanned Antennas," F. E. Goodwin and J. Sur, Hughes Aircraft Co.

(Continued on page 140A)

LINCOLN LABORATORY

continues to augment its staff. We invite inquiries from persons with superior qualifications.

A brochure is available which is generally descriptive of Lincoln Laboratory programs in the following areas:

AICBM SYSTEMS STUDIES

NEW RADAR TECHNIQUES

RADIO PHYSICS

SOLID STATE Physics, Chemistry, and Metallurgy

COMMUNICATIONS:

- **Techniques**
- **Psychology**
- **Theory**

INFORMATION PROCESSING, DIGITAL COMPUTER TECHNOLOGY

Research and Development

M.I.T. LINCOLN LABORATORY

BOX 16 · LEXINGTON 73, MASSACHUSETTS

Martin Lacrosse Plays Deadly Game

Mobile as a chess queen, quick as a rapier thrust and as lethal as brass knuckles, the Martin Orlando Lacrosse is a handy weapon in a scrap. Developed, designed and built for the U. S. Army, the Lacrosse can flit like a ghost behind the battle area, fire in the general direction of the target and be pin-pointed by a forward guidance station.

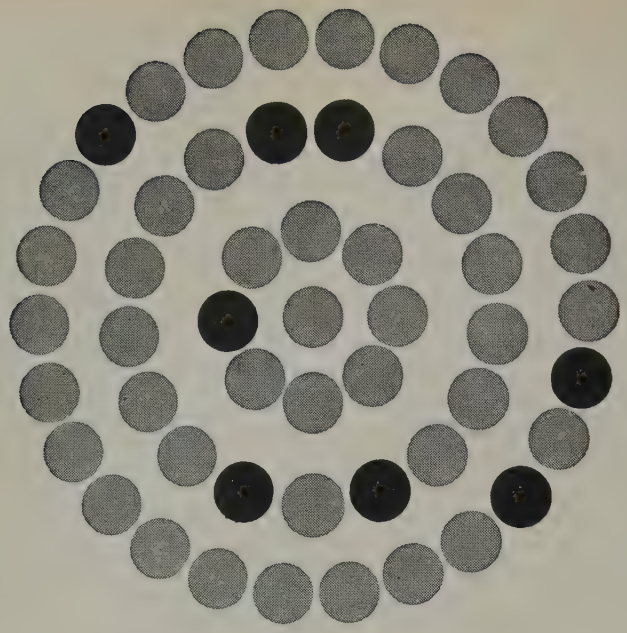
The Lacrosse's ability to change its mind while in high velocity flight is another in the growing list of accomplishments by the men of Martin Orlando. Additional prime contracts include the Bullpup, air-to-surface missile, the Pershing, selective-range surface-to-surface missile and the Missile Master, electronic detection and control system for missile batteries.

Blue sky vision plus feet on the ground know-how has projected Martin Orlando to its place of leadership in electronics and missiles. Martin Orlando needs men with gray matter, the solid propellant needed to reach ever higher degrees of sophistication.

Immediate openings at senior level exist for Electronic Engineers, Physicists and Electrical Engineers in these areas: pulse circuitry, electronic packaging, transistor circuitry, electronic production test equipment, digital and analog computers. Also opportunities for men experienced in calculating solid state parameters, molecular distribution and quantum mechanics. Send confidential resume to: J. F. Wallace, Director of Professional Staffing, The Martin Company, Orlando **45,** Florida.

MARTIN
ORLANDO

Ft. Sill, Okla., June, 1959—The first two U. S. Army Battalions employing highly accurate Lacrosse surface-to-surface missiles will be activated this month. Martin Orlando is supplying all the material required for the activation, including maintenance, training devices, launchers and missiles.



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TECHNICAL WRITERS AND ILLUSTRATORS, QUALITY CONTROL ENGINEERS, RELIABILITY ENGINEERS
Motorola also offers opportunities at Riverside, California and Chicago, Illinois

Professional Group Meetings

(Continued from page 138A)

Washington—March 10

"The Present Situation in Masers," M. A. Garstens, Naval Res. Lab.

Military Electronics

Boston—March 10

"Combat Surveillance," J. M. Gavin, Arthur D. Little, Inc.

Long Island—October 28

"Shipboard Guided Missile Weapon System Simulators," A. P. Vigliotta, U.S. Naval Training Device Center.

"The Master Terrain Model System," J. Stieber, U.S. Naval Training Device Center.

"AERO 21B Aircraft Tail Turret System Operators Trainer," I. Friedland, U.S. Naval Training Device Center.

San Francisco—March 10

"Research Program at Wright Air Development Center Concerning the Human Factors in Space Travel," S. T. Wray, USAF.

Nuclear Science

Albuquerque-Los Alamos—January 27

"Radioactive Decay and Particle Interaction," C. D. Broyles, Sandia Corp.

Connecticut—February 25

"Reactor Start-Up Simulation in Analog Facilities," L. M. Johnson, Combustion Eng., Inc. (Nuclear Div.).

Production Techniques

Boston—February 24

"Modern Printed Circuit Techniques," R. G. Zens, Printed Electronics.

San Francisco—February 24

"Problems in Design of Production Electronic Equipment," J. Hall, Dalmo-Victor Co.

Reliability and Quality Control

Los Angeles—February 16

"How parts are made to meet warranty clauses of 5 years of continuous operation. Design, process controls and cost factors," R. F. Edwards, Internatl. Rectifier Corp.

"Contracts and specification—how to negotiate reliability requirements, cost factors, sample sizes," M. A. Patterson, Bendix Corp.

"How to continuously improve design reliability through field feedback," A. L. Gichtin, Hughes Aircraft Co.

(Continued on page 142A)

TUBE ENGINEERS

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IMMEDIATE OPENINGS IN RESEARCH & DEVELOPMENT

MISSILE CONTROL SYSTEMS BS or MS degree in EE. For technical direction and coordination of installation and testing of Polaris weapons systems on nuclear powered submarines. 2 to 5 years experience desired in fire control, navigation, guidance or launching systems.

CIRCUITS & EQUIPMENT Development of circuits and equipment in conjunction with missile and navigation systems installations aboard submarines. Requires EE degree with advanced courses and experience in servomechanisms.

ELECTRICAL SYSTEMS 1. 5 years experience on shipboard electrical systems design. For design of electrical power and control systems for prototype nuclear propulsion systems for a marine gas cooled reactor plant. 2. EE, ME or Physics degree required. Responsible for conceptual engineering and systems analysis of large complex devices employing a combination of electrical, electronic, electromechanical, hydraulic and pneumatic systems. Should be familiar with servomechanisms theory, experienced in use of analog or digital computers as a design tool, and have a good grasp of mathematics. Will work on proposal preparations, feasibility studies and execution of hardware contracts.

SERVOMECHANISMS For engineering design of servomechanisms in both the instrument and multiple horsepower class. Will interpret performance specifications and be responsible for design of a system in accordance with the specifications, including stability studies, and the calculation of other performance criteria.

COMPUTERS Responsible for conceptual engineering and programming of special purpose digital and analog computers. Should be familiar with system engineering, experienced in programming and check systems for both analog and digital computers, with good grasp of simulation techniques. Requires EE, Physics or Mathematics degree.

CIRCUITS Responsible for conceptual and production engineering of electronic equipment. Familiar with servomechanisms and analog computer theory. Experienced in use of semiconductors, magnetic amplifiers and vacuum tube circuit elements; good grasp of mathematics; EE or Physics degree.

OPERATIONS RESEARCH—PhD in physical sciences required. To be responsible for operations research studies of submarine and anti-submarine weapons systems.

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Electric Boat Division's location—just half way between New York and Boston on the Connecticut shore near New London—provides excellent living and working conditions. To arrange convenient interview appointment at General Dynamics headquarters in New York, or at Electric Boat Division in Groton, send your resume, in confidence, to James P. O'Brien, Technical Employment Supervisor.

GENERAL DYNAMICS
ELECTRIC BOAT DIVISION
GROTON CONNECTICUT

Professional Group Meetings

(Continued from page 140A)

"How to predict reliability in the design development phase—use of reliability testing and analysis," W. X. Lamb, Hughes Aircraft Co.

"Assuring missile reliability in field use—utilizing design and factory reliability measurements. Training field handling personnel. Knowledge of the field environment," J. H. Allen, Space Technology Lab.

"Assuring Electronic Equipment field reliability is maintained. Training, component replacement, spares provisioning, timed failure measurements," I. Doshay, Hughes Aircraft Co.

"How to assure that manufactured items satisfy design reliability specifications, reliability prediction, reliability testing on small samples, cost factors, analysis of test results," R. Douglas, Servomechanisms.

"How to assure that manufactured items satisfy design reliability specifications," J. C. Morey, Hughes Aircraft Co.

Philadelphia—April 7

"Systems Aspects of Reliability," P. Winsor, III, Auerbach Electronics Assoc.

Space Electronics and Telemetry

Albuquerque—March 10

"Information theory as applied to TM," B. Basore, Dikewood Co.

Detroit—March 18

"Ground Guidance Computer of the Atlas Missile," T. R. Thomas, Burroughs Corp.

Space Electronics and Telemetry/Instrumentation

Washington, D.C.—March 17

"Energy Sources for Missile and Space Electronics," T. K. Trigg, Office of the Chief Signal Office.

Vehicular Communications

Detroit—February 25

"Crystal Problems in Split Channel Operation," J. Holmbeck, Northern Eng. Labs.

Los Angeles—March 11

"Electronics and Multi-Purpose Communications in Southern California Edison Company," L. E. Ludekens, S. Calif. Edison Co.

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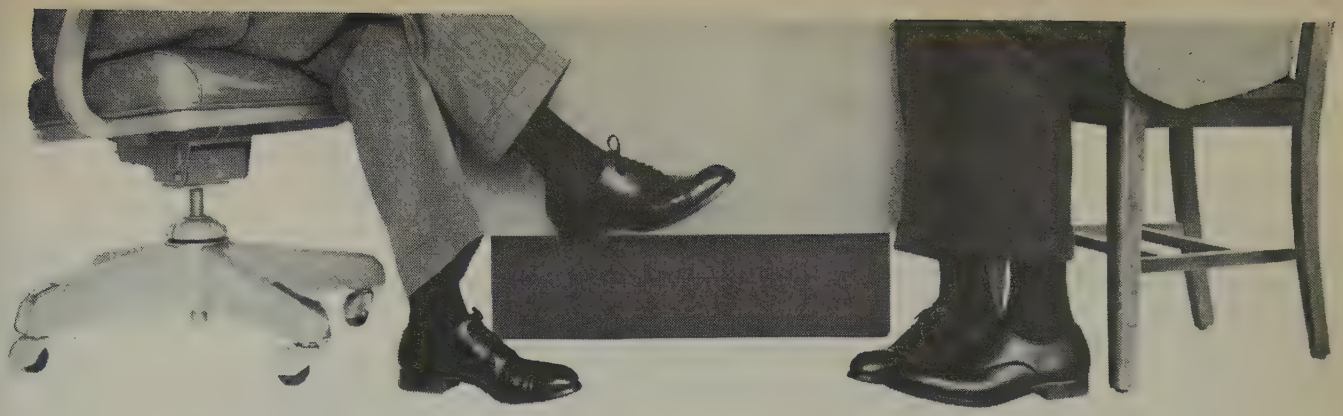

INTERVIEWS for INDIVIDUALISTS

APPLICANT:
"...what I'd like, of course, is an engineering position that's challenging and creative...and, I might add, at a good salary. I know I'm asking for a lot..."

EMPLOYMENT MANAGER:
"Not at Librascope, Mr. Wilcox. We *practice* individualism! We know a man works best with recognition, security, interesting assignments."

APPLICANT:
"But what about advancement? Since I have a goal in mind, what are my chances?"

EMPLOYMENT MANAGER:
"Excellent! At Librascope, we watch ability, not seniority alone. You can advance as fast as your talents permit."

APPLICANT:
"That's what I'm looking for! A chance to show what I can do in Computer Logic Design."

EMPLOYMENT MANAGER:
"You'll have that chance. And you'll be able to follow through on your ideas, as a member of a project team. By the way, I see you have your BS in EE..."

APPLICANT:
"I intend to get my Master's someday..."

EMPLOYMENT MANAGER:
"You can work on it now. We'll pay your tuition at any one of the excellent universities here in Southern California. We encourage continued schooling at all levels."

APPLICANT:
"Sounds good to me! But getting down to specifics, may I ask what kind of problems I might be working on?"

EMPLOYMENT MANAGER:
"Let's see, with your background and talents, you'd probably do well in our Shipboard Equipment Department which is developing fire control computers for the ASROC, SUBROC and POLARIS systems."

APPLICANT:
"That's right in my line!"

EMPLOYMENT MANAGER:
"I thought so. Why don't you talk with some of the engineers you'll be working with. They can tell you more."

APPLICANT:
"I'd like to do that. I met some Digital Computer Engineers at coffee break earlier. They seem like a pretty sharp group."

EMPLOYMENT MANAGER:
You'll find all our engineers are top men. You should hear the bull sessions at lunch! A lot of ideas go into advanced concept study programs from some of those informal..."

APPLICANT:
"Now that's one of the things I'm looking for ...exchanging ideas...time to research...Say! I'm sure Librascope is the place for me."

Contact: **GLEN W. SELTZER, EMPLOYMENT MANAGER**
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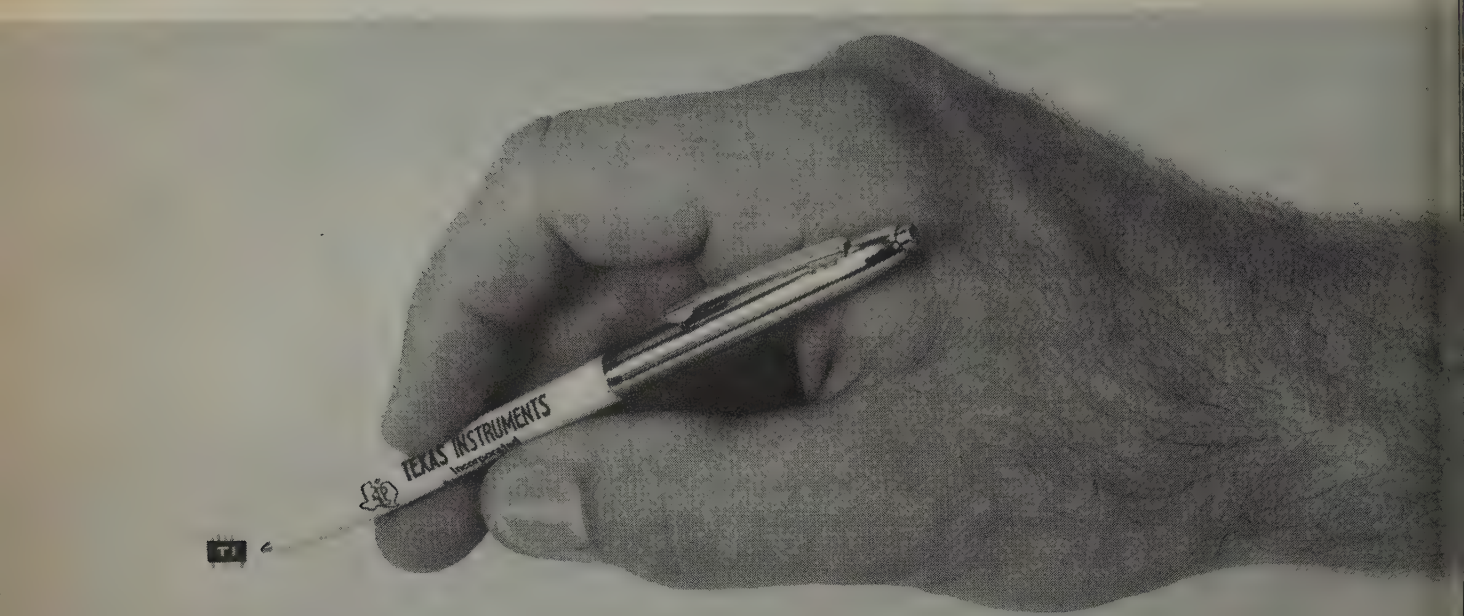


TI's new semiconductor solid circuits measure less than ¼ x ⅛ x 1/32 of an inch and incorporat up to 12 integral electronic components. Complete multivibrator circuit shown. I addition to extreme size and weight reduction, reliability also has been greatly increased

join TI engineers in such challenging programs as micro-miniaturization

TI develops new semiconductor solid circuit with componen densities up to 34 million per cubic foot!

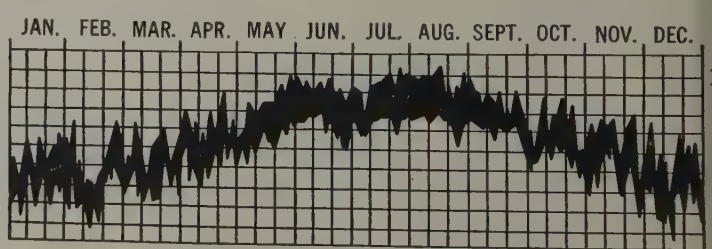
From one of many stimulating research and development programs at Texas Instruments comes another major "first" . . . new semiconductor solid circuits! Born from TI-sponsored research studies, the basic concept was carried through to reality by the Semiconductor-Components division. Utilizing TI developments in semiconductor manufacturing techniques (controlled masking, etching, diffusion), TI has formed diode and transistor elements, as well as passive elements of resistance and capacitance, to provide a complete circuit function normally requiring up to 12 components!

Such significant developments naturally result from TI's great emphasis on creative ability and freedom of professional expression. *You'll find many challenging opportunities at Texas Instruments where such technological advances are a frequent occurrence.* At the Apparatus division, weight and size are critical factors in its missile and aircraft electronic and electromechanical systems. You may explore new possibilities for making these systems even smaller and more reliable using the new semiconductor solid circuits. Or, with the GeoSciences and Instrumentation division, you may exercise this new concept in circuitry to create new and more compact commercial and industrial instrumentation.

A rewarding opportunity awaits you in one of the many programs now in progress at TI's Central Research Laboratory, Semiconductor-Components, Apparatus, and GeoSciences and Instrumentation divisions.

You will also benefit from TI's up-to-date personnel polici which include profit sharing plan (in 1958, 15% of base ear ings), semi-annual salary and advancement reviews, educ tional assistance, insurance, hospitalization, and retireme programs. You will enjoy the temperate Southwestern clima and the many year-round recreational, amusement and cu tural activities.

To join this fast-moving company at the forefront of scienti technologies, please write to activity of interest shown at righ enclosing a short resume.



(Graph courtesy of Dallas Times Herald, January 7, 19

Dallas' 12-month weather chart shows that temperature averaged 65 in 1958, with humidity at a comfortable low level. Dallas skies a predominantly clear and sunny, devoid of industrial haze or sm

specific career opportunities now open at Texas Instruments

SEMICONDUCTOR-COMPONENTS DIVISION

DEVICE DEVELOPMENT — Develop new semiconductor devices; conduct experimental and theoretical studies on the effects of nuclear radiation on semiconductor materials and devices; evaluate experiments in the analysis of gases and electro-chemistry; conduct physical measurements on semiconductor surfaces; determine the effects of chemical reaction on semiconductor surfaces; studies in device stability, reliability and characterization; materials research and development including crystal growth and crystallography.

CIRCUIT DEVELOPMENT — Transistor circuit design and application; design automatic and semi-automatic test equipment.

MECHANIZATION — Design and develop high speed automatic machinery.

Please write to H. C. Laur, Dept. 1002, P. O. Box 312, Dallas, Texas

APPARATUS DIVISION

ELECTRICAL DESIGN AND DEVELOPMENT ENGINEERS (minimum 3 years experience) To apply technologies of radar, sonar, infrared, magnetics, microwave, telemetry, special-purpose computers, and servos to submarine detection, missile guidance and instrumentation, combat surveillance and reconnaissance, and aerial object detection and tracking. Conduct studies and analyses, and circuit development, electronic and electromechanical component design, transistorization, and miniaturization. Educational requirements: MSEE, BSEE, or BS Physics.

MECHANICAL DESIGN AND DEVELOPMENT ENGINEERS (minimum 3 years experience) Design and develop servo systems, X-Y plotters, strip recorders, optical systems, vibration damping and isolation packages, antenna structures and drives, sonar reels, cooling and heating systems and electronics packaging. Guide drafting, environmental testing, and model making; give consultation to manufacturing engineers to solve project production problems. Environmental studies. Educational requirements: MSME or BSME.

MANUFACTURING ENGINEERS (minimum 1 year experience) Production planning, tooling, and guidance and control of all phases of general production activity, or of an assigned project. Mechanization for short-run equipment manufacture. Educational requirements: BSME, BSEE, or BSIE.

COST ESTIMATING ENGINEERS (minimum 3 years experience) Estimate or supervise estimation of material, labor, tooling, and indirect costing factors on unusual electronic and electronic and electromechanical systems and equipments. Electromechanical manufacturing experience desired. Educational requirements: BSEE or BSIE.

QUALITY CONTROL ENGINEERS (minimum 3 years experience) Establish and maintain standards of quality and inspection methods for all raw materials and manufactured products. Three years experience in statistical methods, manufacturing processes, equipment inspection and/or design with minimum of 1 year in electronics industry. Educational requirements: BSEE or BSIE.

RELIABILITY ENGINEERS (minimum 3 years experience) Assist project engineers during design phase for maximum electronic or electromechanical reliability. Evaluation, selection, and application of components. Estimate system reliability; analyze and recommend corrective action. Experience in equipment design and component application. Educational requirements: MSEE or BSEE.

Please write to John Pinkston, Professional Placement, Dept. 1002, 6000 Lemmon Avenue, Dallas 9, Texas

GEOSCIENCES AND INSTRUMENTATION DIVISION

MANUFACTURING ENGINEER—EE or ME with 2 years or more similar experience in production planning and control.

ELECTRICAL ENGINEER — EE with 3 to 5 years experience in electronic design.

ENGINEER — EE or Physics sustaining engineering of seismic products.

SALES ENGINEER, SEISMIC — Science degree with seismic crew experience, with minimum of 5 years experience.

SENIOR ENGINEER — EE with 5 years in electronic circuitry design and development.

INDUSTRIAL ENGINEER — IE with 3 to 5 years experience in Industrial Engineering or related work.

SENIOR ENGINEER — EE or ME with experience in electrical products, particularly in commercial and industrial areas.

MECHANICAL ENGINEERS — ME with instrument field experience.

Please write to Dave Turner, Dept. 1002, 3609 Buffalo Speedway, Houston, Texas

CENTRAL RESEARCH LABORATORY

HEAD—PHYSICS SECTION— 4 to 5 years experience in semiconductor physics and proven ability to direct a variety of technical projects. Responsible for directing work on the measurement and understanding of electrical, thermal, magnetic, optical, and transport properties of semiconductors. Educational requirement is PhD in Physics.

HEAD—DEVICE SECTION— 4 to 5 years experience in semiconductors plus experience in group leadership and proven ability to supervise a variety of technical projects. Will be responsible for directing work on design, fabrication and evaluation of new solid state devices. Educational requirement is MS or PhD in either Physics or EE.

SOLID STATE THEORIST — Responsible for the understanding and interpretation of the physical properties of semiconductors and other solid state materials. Educational requirements: PhD in Physics with concentration in quantum mechanics. Solid state experience desirable but not necessary.

DEVICE THEORIST — Responsible for the design of new solid state devices and interpretation of their characteristics in terms of physical and fabrication parameters. Educational requirement is PhD in Physics or EE, or MS with 2 to 3 years experience in solid state device theory.

SEMICONDUCTOR TECHNOLOGY — Responsible for the design and interpretation of experiments on the technology of semiconductors, including impurity diffusion and alloying. Educational requirement is PhD in Physical Chemistry or Metallurgy. Experience requirement: 3 to 4 years experience in semiconductor technology.

THEORETICAL PHYSICIST— 2 to 3 years experience in electron or nuclear magnetic resonance with interest and background to perform theoretical analysis of EMR and NMR to develop possible new types of magnetometers or to make significant improvement in present types. Sufficient experimental background and interest to assist in translating theoretical results into experimental projects.

PHYSICISTS — Either MS or PhD with 1 year minimum experience in the fields of superconductivity and low temperature physics. Should be acquainted with conventional techniques of transferring and handling liquid helium and designing circuits and instrumentation for studies in this area.

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Advanced study opportunities are available in the area

Section Meetings

AKRON

Annual Prize Competition, four papers by Univ. of Akron students; 1st Prize: "Electro-Luminescense," K. Thompson; 2nd Prize: "Function Generators," E. Anderson; other topics: "Plasma Generation," M. Kriston; "Hospital Engineering," D. Nosser; Joint with AIEE and Univ. of Akron students; 3/10/59.

ALAMOGORDO-HOLLOMAN

Annual Meeting and Installation of Officers; 3/16/59.

ATLANTA

"IRE National Convention," K. Su and C. James, Ga. Tech.; "Region III IRE Meeting," S. R. Smith, Lockheed Aircraft; 4/3/59.

BALTIMORE

"Space Communications," P. Costruccio, Westinghouse; "Fellow" Awards Presentation to T. P. Kinn and D. D. King; 3/17/59.

BEAUMONT-PORT ARTHUR

Port Arthur College and KPAC TV Mobile Unit, Tour, talk by E. D. Coburn, PCC; 3/20/59.

BINGHAMTON

"Electronics in SAC," M. J. Stublarec, 8th Air Force; 4/13/59.

BUFFALO-NIAGARA

"Ontario Hydro Electric Power System," Movie and technical description; Sir Adam Beck Niagara Generating Station No. 2, Tour; 4/8/59.

CEDAR RAPIDS

"Arctic Oceanography and the 1958 Cruise of the Skate to the Arctic Ocean," E. C. LaFond, Naval Electronics Lab.; "Lunar Probe and Satellite Tracking Stations in Puerto Rico and Goldstone, Calif.," Slides and talk, D. L. Holzschuh; 3/18/59.

CENTRAL FLORIDA

"The Application of Dielectric Materials to Microwave Absorbers and Luneberg Lenses," E. F. Buckley, Emerson & Cuming, Inc.; 1/15/59.

"Electrostatic Printing," Sound Film, "The Stronger Link," R. M. Wilson, Burroughs Corp.; 2/19/59.

"TETRAC, The Tension-Truss Antenna Concept," H. Holland, Narmco Mfg. Co.; 3/19/59.

CLEVELAND

"Compatible FM Multiplex Stereo Transmission," M. G. Crosby, Crosby Labs.; 3/11/59.

COLUMBUS

"Operation of the OSU Heart/Lung Machine," T. D. Drisbell, Ohio State Univ. Hospital; 4/14/59.

CONNECTICUT

"White Alice Communications Network in Alaska," R. Stecker, Western Electric; 10/16/58.

"Airborne Doppler Systems," N. Engle, G.P.L. Lab.; Election Subs. Officers, Joint with Fairfield County Subsection; 12/4/59.

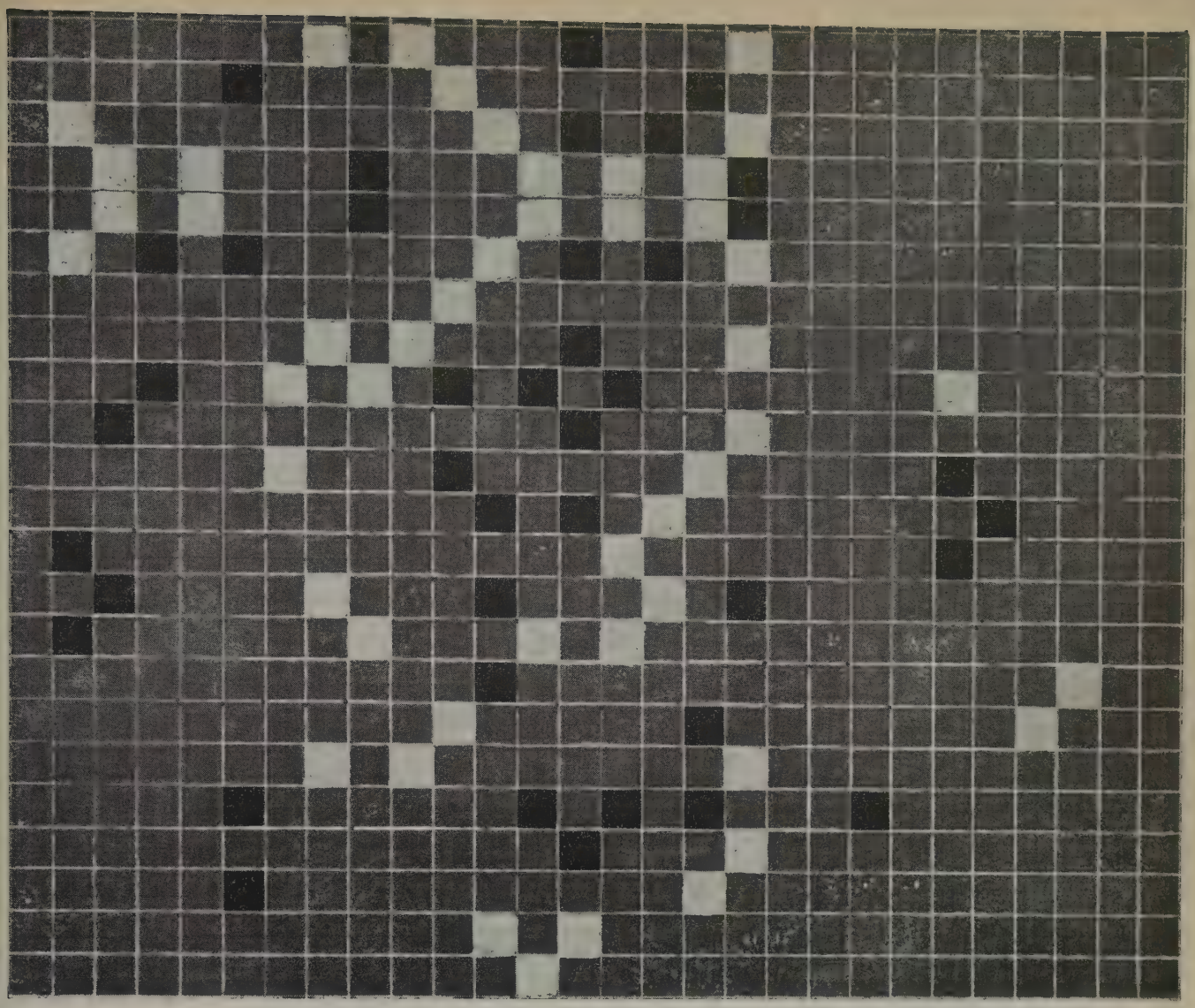
"Compatible Stereo Broadcasting," M. G. Crosby, Crosby Labs.; Fellow Awards Presentation to G. C. Grammer, ARRL and P. F. Ordung; 1/15/59.

Tour, Digital Computer Lab., talk, W. Ramshaw, Computation Lab., UAC; 2/10/59.

DALLAS

"Moon Probes," J. R. Scull, Jet Propulsion Lab., Calif. Inst. of Tech.; Joint with Dallas Chapter of American Astronautical Society; 4/7/59.

(Continued on page 148A)



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If your interests as an engineer lie in electronic systems engineering, in data processing and communications, you will find in this project unusual opportunity to express imagination and creative competence, in a degree surpassing anything previously undertaken in computer engineering.

To obtain information on engineer openings write A. J. Crawford, Personnel Manager. A resume of your education and experience is essential. An interview will be arranged at your convenience.

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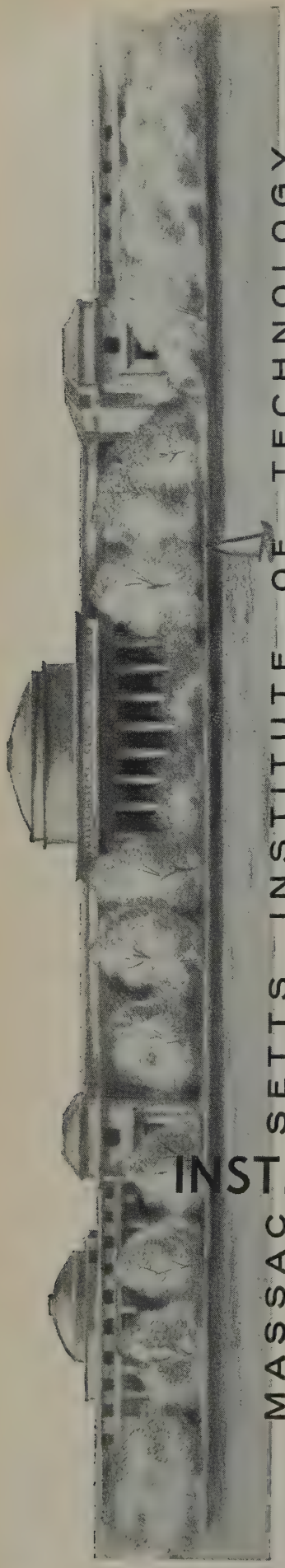

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U. S. Citizenship Required

Section Meetings

(Continued from page 146A)

DETROIT

"Automatic Reduction of Telemetered Data from the Vanguard Missile," W. B. Poland, Naval Research Labs.; Joint with PGTRC; 1/16/59.

"New Developments in Solid State Devices," K. G. McKay, Bell Tel. Labs.: Fellow Presentation to L. N. Holland; 2/20/59.

"Plasmoids," W. H. Bostick, Stevens Inst. of Tech.; 3/20/59.

EMPORIUM

"Properties of Getters in Electronic Tubes," J. E. Wagener, Kemet; 3/17/59.

"The Story of The Cutting Edge," illustrated Lecture, Do All Company; Joint with ASTE, AIEE; 4/2/59.

EVANSVILLE-OWENSBORO

"Solid State Components, Boon or Bane to the Electronic Engineer," P. Russell, G.E. Co.; 3/11/59.

"Controlled Thermonuclear Fusion," W. S. Emmerich, Westinghouse Research Labs.; 4/8/59.

FORT HUACHUCA

"Automatic Data Processing in the Field Army," H. L. Shoemaker, Ramo-Wooldridge; 3/30/59.

FORT WAYNE

"Development of a System for Electronic Control of Highway Vehicles," L. E. Flory, RCA Labs.; 3/5/59.

"Transistor Audio Amplifiers," A. D. Evans, Texas Instruments, Inc.; 4/2/59.

FORT WORTH

"The Engineer's Problem in Communicating with Management," F. V. Long, Texas Eastern Transmission Corp.; Joint with AIEE Fort Worth Subsection; 1/20/59.

"Application of Dielectric Materials to Microwave Absorbers and Luneberg Lenses," E. F. Buckley, Emerson & Cuming; 2/17/59.

"Nuclear Reactor Instrumentation," J. R. Gardner, Convair; Joint with Dallas Section; 3/10/59.

HAMILTON

"Stereo, Its Rise and ?," Mr. Gordon, Dominion Electrohome Industries Ltd.; 3/9/59.

HOUSTON

Plant Tour of Southwestern Industrial Electronics; 3/17/59.

INDIANAPOLIS

"Engineering Education in Russia," R. A. Morgan, Purdue Univ.; 2/28/59.

ITHACA

"Physical Problems Encountered in Solid State Amplifiers," M. W. P. Strandberg, M.I.T.; 4/8/59.

KANSAS CITY

Annual Student Paper Competition Prize Awards, J. A. Costelow; "Single Broadcast Station Stereo System," R. E. Grillot, Univ of Kansas; "Boolean Algebra and Elementary Application to Switching Circuit Design," R. D. Moyer, Kansas State Univ.; "Conversion and Transmission of FM/FM Telemetered Data," J. B. Shism, Central Technical Institute; 3/10/59.

LITTLE ROCK

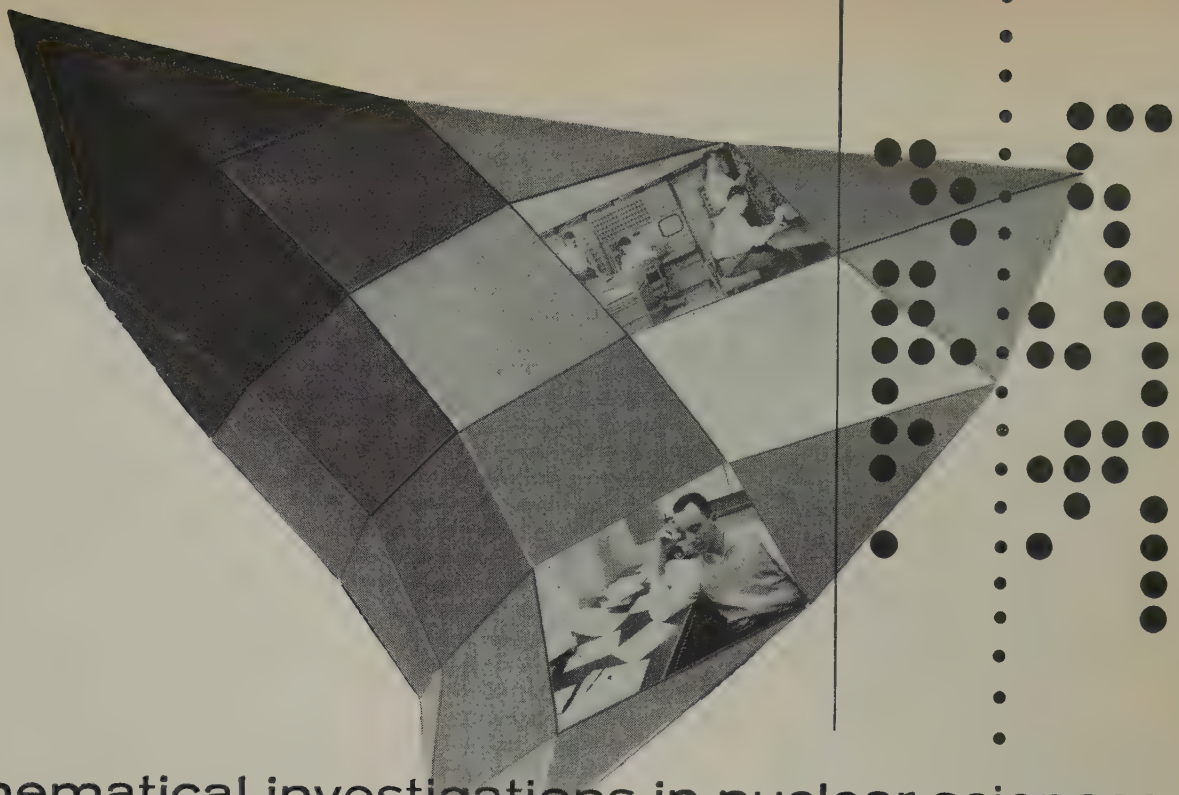
"Tubes vs Transistors," J. W. Rush, G.E. Co.; 3/17/59.

LONDON

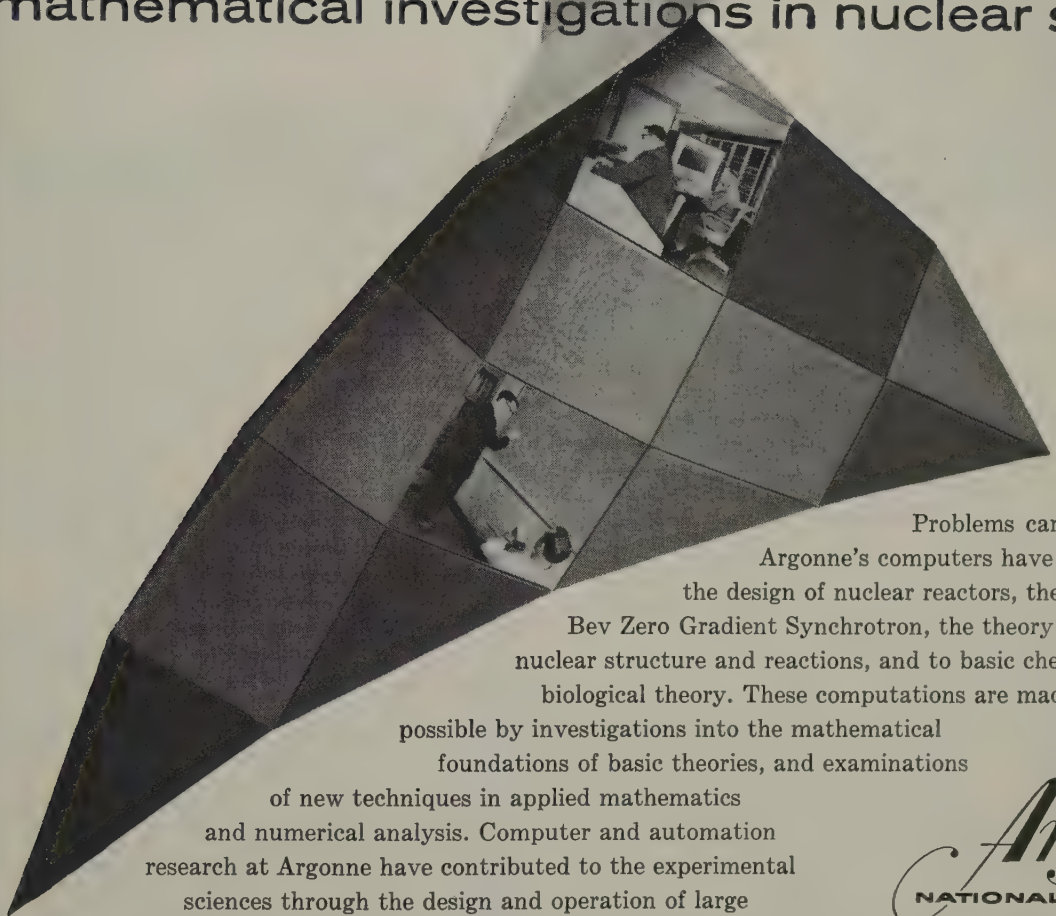
"Geneva Conference on Atomic Energy," J. MacDonald, Victoria Hospital; 1/20/59

"Computers," B. LeBer, Ryerson; "Pulse Code Modulation," P. Ozawa, Univ. of Toronto; "Nuclear Magnetic Resonance," R. Ollerhead, Univ. of Western Ontario; "Electronic Techniques for Flash

(Continued on page 150A)



mathematical investigations in nuclear sciences



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Section Meetings

(Continued from page 148A)

Absorption," R. Koehler, Univ. of We tern Ontario; 2/17/59.

LOUISVILLE

"Conelrad System Operation and Apparatus," O. Towner, WHAS, WHAS-TV Inc.; Joint with AIEE; 3/12/59.

MIAMI

"Direct Distance Dialing," W. C. Runge, Southern Bell; 3/20/59.

NEW ORLEANS

"A 20 Watt Transistorized Amplifier," C. Campbell, La. State Univ.; "A Transformerless 10 Watt Transistorized Amplifier," W. C. Sewell, La. State Univ.; "A Portable 90 Watt Transistorized Transmitter for Use with a 12 V.D.C. Power Supply," Mr. Malone; Student Papers.; 4/1/59.

NEW YORK

"Electronics in Meteorological Observing and Forecasting," D. R. Harris, Aero Meteorological Investigations, U.S. Weather Bureau; 10/1/58.

"Written Communication Without Distortion," W. Davis, Science Service; 11/5/58.

"The Use of Electronics in Vehicular Traffic Control," R. W. Cottain, NYC Dept. of Traffic; "Data Analysis Techniques in Expressway Planning," L. Lawton, NYC Dept. of Traffic; 12/3/58.

"An Introduction to Nuclear Reactors and Their Control," M. S. Silberstein, Nuclear Development Corp. of Am.; 1/7/59.

"A Unified Approach to Magnetic Amplifier Theory," G. M. Attura, Industrial Control Co.; 2/4/59.

Dinner Meeting to honor new Fellows and Award winners; "Electronics is Scientific Engineering," Dr. Ernst Weber, IRE President; 3/4/59.

NORTH CAROLINA

"Technical Publication's Part in Government Contracts," W. G. McAvoy, Western Electric Co.; 3/20/59.

"Data Transmission Over VF Channels," L. A. Weber, Bell Tel. Labs.; 4/17/59.

NORTHERN NEW JERSEY

"Electronics in the USSR," A. Jensen, (retired) Bell Tel. Labs.; 2/10/59.

"The Dew Line," Film, W. G. Donaldson, Federal Electric Co.; 3/11/59.

OMAHA-LINCOLN

"Dawn of the Age of Space Flight," D. C. Romick, Goodyear Aircraft; Joint with AIEE Neb. Section and Univ. of Neb. Jt. Student Branch; 4/16/59.

OTTAWA

Fellow Award Presentation to H. VonBaeyer, by A. Barclay, Director, Region VIII; 3/12/59.

PHOENIX

"History of Keiser Electronics," L. Shuck, Keiser Electronics Lab.; "Compatible Single Sideband," J. Schwartz, Keiser Electronics Lab.; 3/20/59.

PORTLAND

"How to Select a Data System," M. L. Klein, Franklin Electronics; 3/19/59.

PRINCETON

"Recent Advances in the Theory and Application of Magnetic Materials in Electronics," L. C. Hogan, Motorola Semiconductor Div.; 4/9/59.

REGINA

"Behind the Scenes in Direct Distance Dialing," J. A. Funk, Sask. Government Telephones; 3/5/59.

(Continued on page 152A)

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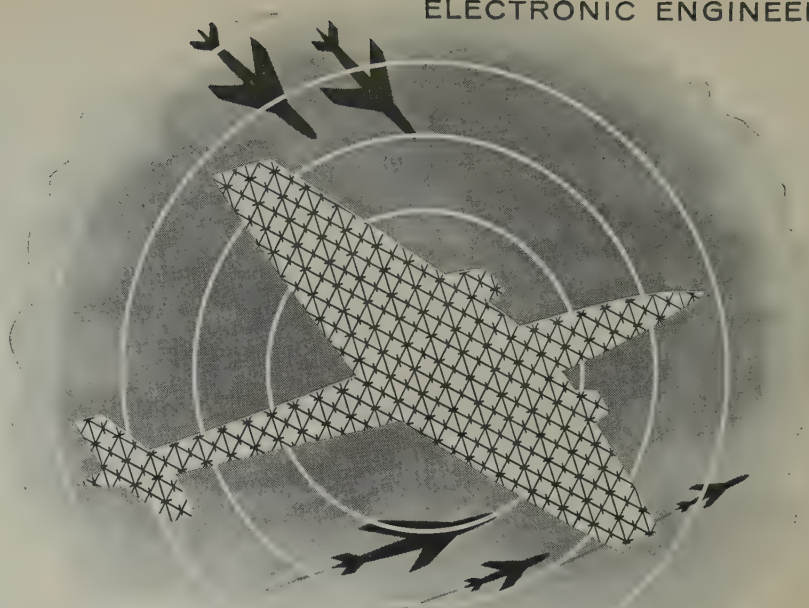

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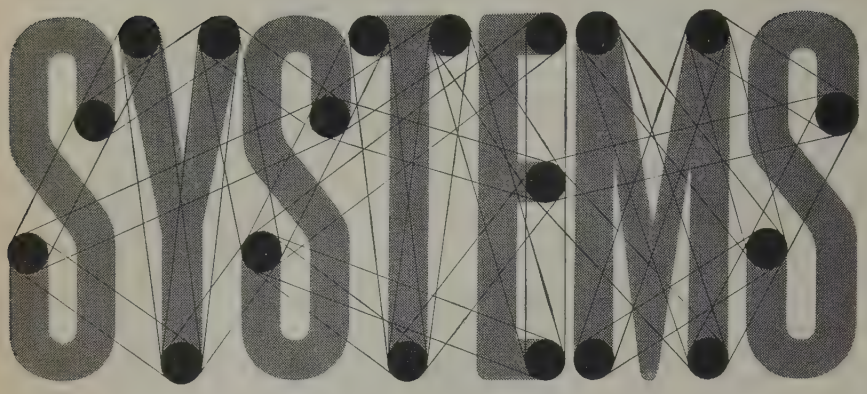

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Section Meetings

(Continued from page 150A)

SACRAMENTO

"The Electron Microscope," C. R. Zercher, RCA; 1/29/59.

"Tube Life and Service Ratings, How to Make Them Better," W. Drew, Calif. Tube Labs.; 2/26/59.

ST. LOUIS

"Medical Electronics," A. S. Gilson, Jr., Wash. Univ. Medical School; 2/17/59.

"Future Circuit Aspects of Solid State Phenomena," D. A. Jenny, Exploratory Research Group, RCA Labs.; 3/17/59.

SAN ANTONIO-AUSTIN

"Convolution as a Modulation Process," F. X. Bostick, Jr., Electrical Engineering Research Lab., Univ. of Texas; 3/18–19/59.

"Education in the Electrical Age," Dr. Ernst Weber, IRE President; 4/9/59.

SCHENECTADY

"Parametric Amplifiers of the Fast Electron Wave," R. Adler, Zenith Radio Corp.; 3/10/59.

SHREVEPORT

Annual Student Papers Contest, La. Tech Jt. IRE–AIEE Student Branch; IRE Student Paper Award: "A Saturable Core Reactor," C. D. Crain; other papers; "Single-Sideband is the Answer," D. E. Walker; "The Kahn Compatible Single-Sideband System as a Broadcast Transition," A. J. DeVilbiss; Jt. with Shreveport and Monroe AIEE Sections; 3/10/59.

"Military Communications Relating to the SAGE System," W. H. Thomason, Southern Bell Tel. & Tel. Co.; 4/7/59.

SOUTHERN ALBERTA

"Work at Sulphur Mountain Laboratory," B. G. Wilson, Univ. of Alberta; 10/23/58

"A Microwave System in the Canadian Rockies," illustrated talk by G. F. C. Weedon, Canadian Motorola Electronics; 11/25/58.

"Project Janet," P. A. Forsyth, Univ. of Saskatchewan; 1/26/59.

SOUTH CAROLINA

"The Seasons," E. D. Simons, Planetarium, Charleston Museum; 3/30/59.

SYRACUSE

"Engineering Management," R. W. Hodgers, G.E. Co.; Presentation of Fellow Awards to: W. E. Good, E. F. Herzog and W. R. Lepage by Dr. Ernst Weber, IRE President; 3/5/59.

"The SAGE Story," H. W. Webster, Syracuse Air Defense Sector; 4/2/59.

TOLEDO

"Applications and Technical Considerations of RF Paging Systems," R. Martin; "Technical Problems Encountered in the Development and Marketing of the Pagemaster Transmitter and Receiver Equipment," K. Ozone, Stromberg-Carlson; 2/12/59.

The 81-D1 Automatic Switching Center, a Demonstration, R. Hagman, The Ohio Bell Tel. Co ; 3/12/59.

TORONTO

"Communication Systems in Brazil," G. M. B. Will, G.E. Co., Ltd.; "Formation of Professional Group in Communication Systems," F. Ford, Canadian G.E. Co., Ltd.; Nomination Night; "Gateway to the Mind," Film, Bell Telephone; 4/6/59.

TUCSON

Annual Student Papers Presentation, First Prize: C. Blankenship, "A Transistorized DC Amplifier"; Second Prize: E. R. Jones, "A New

(Continued on page 154A)

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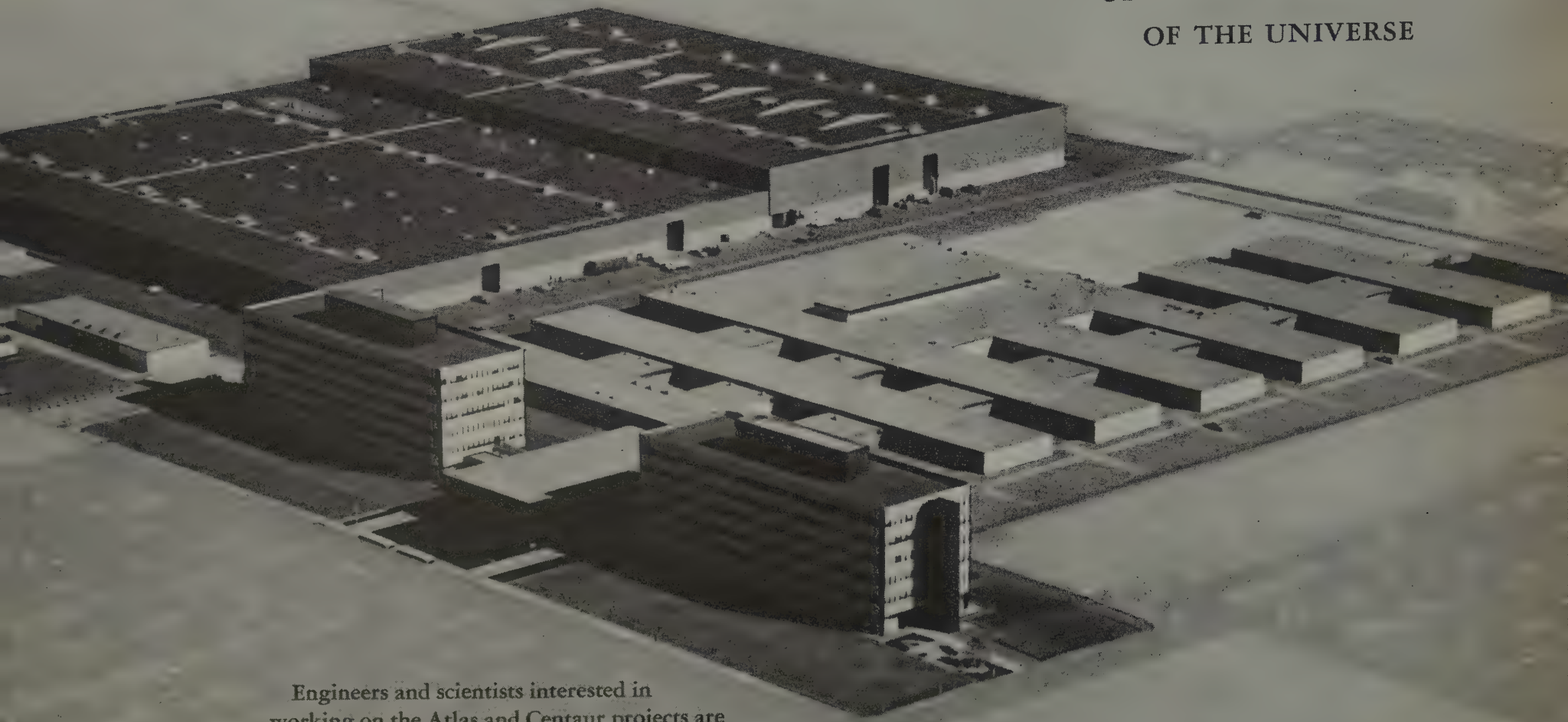

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Section Meetings

(Continued from page 152A)

Way to Generate a Single-Sideband Signal"; Other papers: "Construction and Description of a Communications Model," F. L. Porter, Jr; "The Student's Views on Some Problems Affecting Engineering Education," L. A. Folliet, co-author G. E. Tobey; students of Univ. of Ariz; 4/13/59.

TULSA

"Infrared," O. A. Becklund, Texas Instruments; 2/19/59.

"Space, Radiation, and Environment," J. J. Meny, Atomic Associates, Inc.; 3/19/59.

VANCOUVER

Conducted Tour of Univ. of British Columbia: "Nuclear Magnetic Resonance," M. Lipsicas, Physics Dept.; "Van de Graf Generator," G. Jones, Physics Dept.; "Electron Magnetic Resonance Spectrometer," A. Horsefield, R. Grant, Chemistry Dept.; Demonstration: Techniques of Neuro-Surgery in Studying Tranquillizer Drugs, G. Ling, Pharmacology Dept.; Special Electronic Equipment for Measuring, H. Ayres; 10/20/58.

"Technical Aspects of Videotape Recording," J. L. Middlebrooks, KING Broadcasting Co.; 11/17/58.

"The Reddy Game—A Computer for Playing NIM," R. Cuthbert, U.B.C.; 12/15/58.

"Studio Practice and the 4½" Image Orthicon," L. C. Harrop, CBUT, The Canadian Broadcasting Corp.; 1/12/59.

"Department of Transport Radio Navigational Aids," W. K. Newton, Radio Div., Dept. of Transport; 1/21/59.

Student Paper Awards, First: John McDonald, "Magnetic Core Memories"; Second: M. K. Spencer, "Electronic Sound Effects including Tremolo, Echo Chamber and Vibrato"; Third: "Four Layer Semi-Conductor Diodes & their Application"; R. A. Ward; Fourth: J. H. Collin, "Electronic Business Machines"; students of Univ. of British Columbia; Joint with AIEE Student Branch; 2/16/59.

VIRGINIA

"The Fall of the Law of Conservation of Parity," F. L. Hereford, Jr., Univ. of Va.,

WESTERN MASSACHUSETTS

"Development of Artillery to Guided Missiles," E. B. Canfield, G.E. Co., 3/9/59.

"Coordination of R&D in the Field of Electronic Parts and Materials," E. R. Petzing, Advisory Group on Electronic Parts; 4/3/59.

WICHITA

"Methods and Measurements in Acoustics," Q. Brakebill. Boeing Airplane Co.; 3/17/59.

WINNIPEG

"A New Level of Predictable Tube Performance," D. Simpkins, Rogers Electronic Tubes and Components; 2/24/59.

"Stereophonic Broadcasting and Recording," G. Thompson, Northern Electric Co.; 3/2/59.

SUBSECTIONS

BUENAVENTURA

"Pacific Missile Range, Ramifications of the Missile Program," A. B. Focke, Pac. Missile Range; "Stereo Reproduction," J. K. Hilliard, Altec-Lansing Corp.; 3/11/59.

BURLINGTON

"Stereophonic Reproducer for Phonographs," J. P. Overlay. Radio Mfg. Engineers Inc.; 4/1/59.

(Continued on page 156A)

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Section Meetings

(Continued from page 154A)

EASTERN NORTH CAROLINA

Annual Meeting and Election of Officers; 3/13/59.

"Glass in Electronic Application," G. W. McLellan, Corning Glass Works; 4/10/59.

FAIRFIELD COUNTY

"Airborne Doppler Systems," N. Engel, Gen. Precision Labs.; 12/4/58.

"New Developments in Semi-Conductor Devices," B. J. Rothlein, Sperry Rand Corp.; 1/29/59.

"System Considerations in Design of On-Line Data Processing," S. Levine, Teleregister Corp.; 2/26/59.

GAINESVILLE

Election of Officers for 1959–1960. "Electronic Control of U. of F. Nuclear Training Reactor," J. E. Stubbs, Univ. of Fla.; 4/8/59

KITCHENER-WATERLOO

"Electronic Music," H. LeCaine, Natl. Research Council; "Electronic Music from White Noise Source," J. Bowsher, Natl. Research Council; 3/16/59.

"Microwave Communications and Plasmas in Hypersonic Flight," O. T. Fundingsland, Raytheon Mfg. Co.; 4/20/59

LANCASTER

"Magnetic Tape Recording of Color Television Signals," J. L. Grever, RCA; 4/14/59.

LAS CRUCES-WHITE SANDS

"Satellite Experimentation at California Tech," W. A. Fowler, Calif. Inst. of Tech.; 3/19/59.

LEHIGH VALLEY

"Astronomy in the Radio Spectrum," T. P. McCullough, U.S. Naval Research Lab.; Presentation of Fellow Award to: A. E. Anderson, by Mr. Auerbach; 3/18/59.

MEMPHIS

"Electronics in Infra Red Systems," J. J. Freymuth, Southwestern Univ.; 3/18/59.

NEW HAMPSHIRE

"Topology in Circuit Theory," S. Mason, MIT; 12/3/58.

"Stereo Sound Systems," D. R. VonRecklinghausen, H. H. Scott, Inc.; 1/22/59.

"Reliability Program for R&D Projects," E. H. Dertinger, Raytheon Mfg. Co.; 4/8/59.

NORTHERN VERMONT

"Magnetic Materials," a Talk by Mr. Cushman, Sprague; 3/16/59.

PANAMA CITY

"Infrared," D. J. Edwards, Instrument Development Lab.; 3/10/59.

READING

"The History of the Semi-Conductor Industry," R. F. Lipscomb, Western Electric Co.; 3/25/59.

SAN FERNANDO VALLEY

"Secrets of Stereo," Dr. Frayne, Westrex Corp.; 3/11/59.

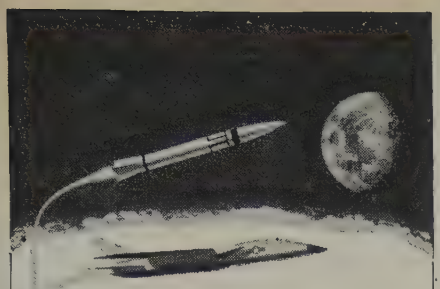
Sodium Reactor Experiment, Film and Tour, R. Connors, Atomics International; 4/8/59.

SANTA ANA

"Friend—Your Watch is Running Slow," R. Leighton, Calif. Institute of Tech.; 3/18/59.

SANTA BARBARA

"Auroral Effects on Communication," A. Peterson, Stanford; 3/9/59.



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(Continued on page 160A)

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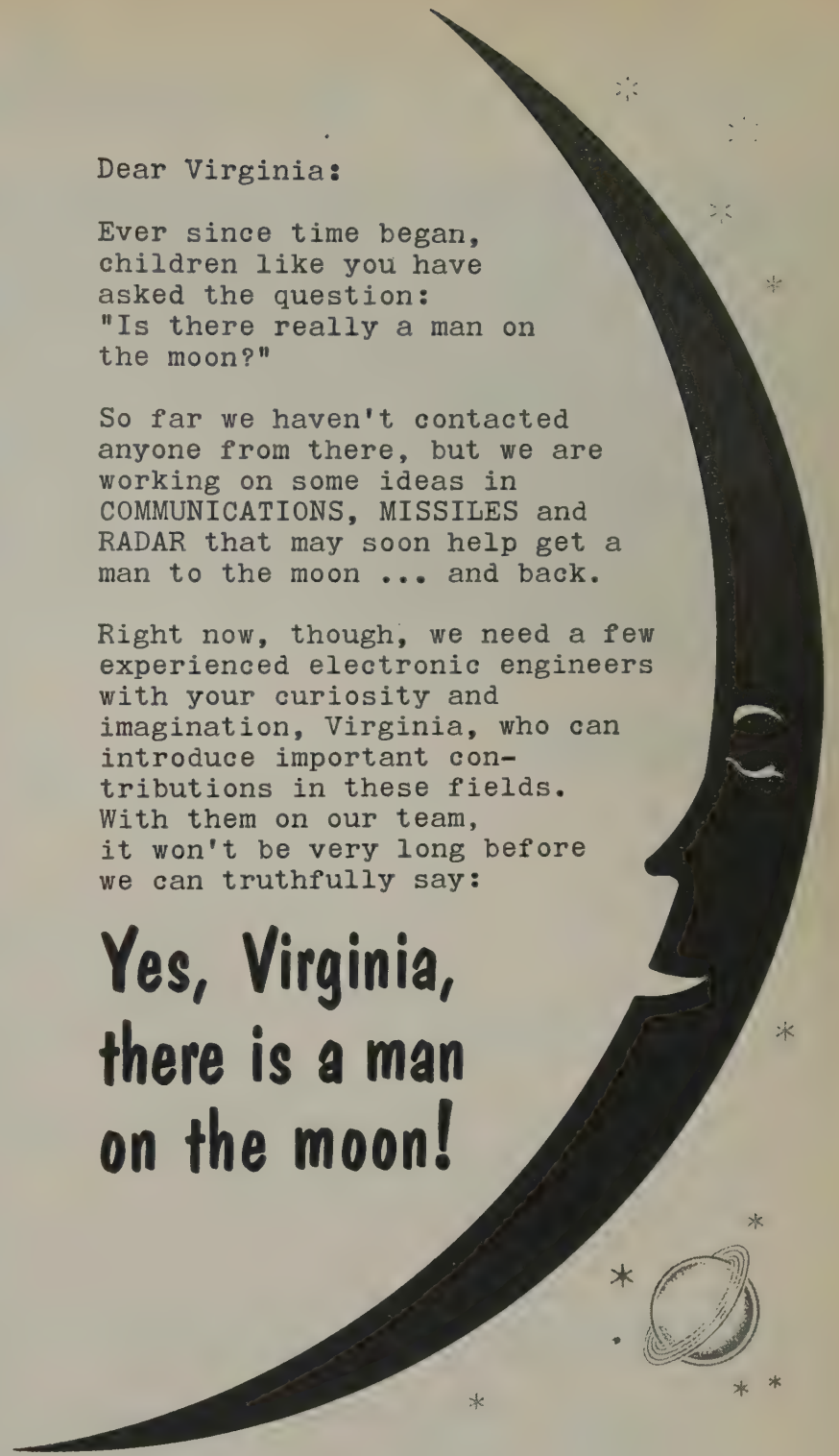
Yes, Virginia, there is a man on the moon!



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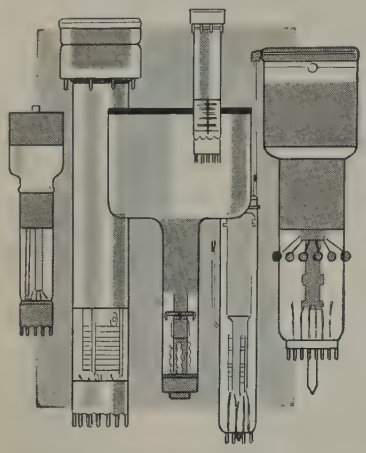

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(Continued from page 160A)

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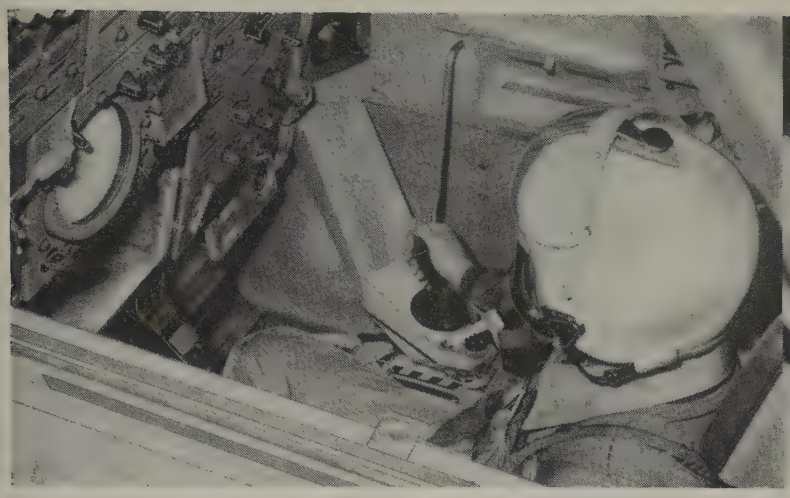

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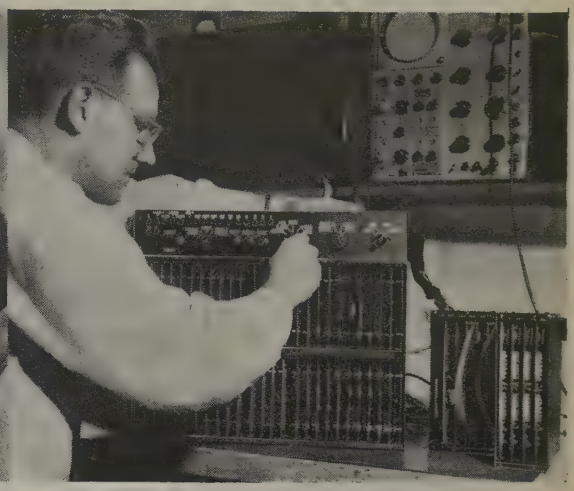

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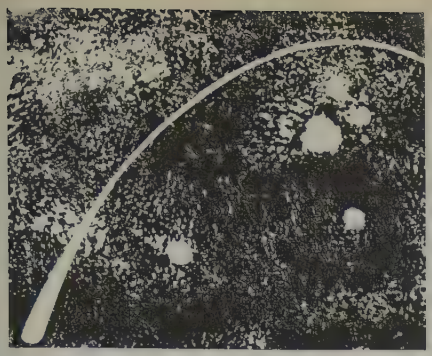

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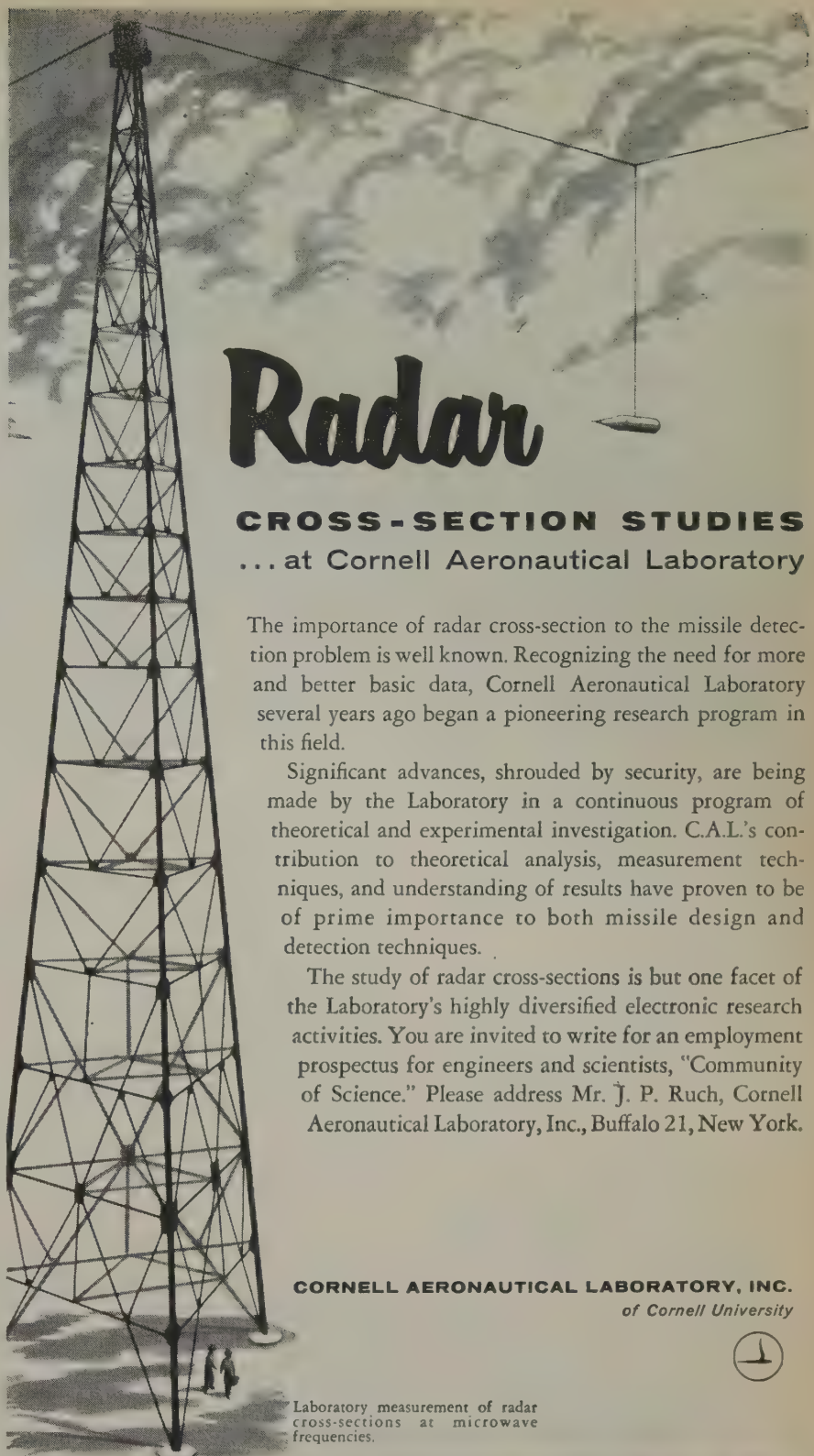

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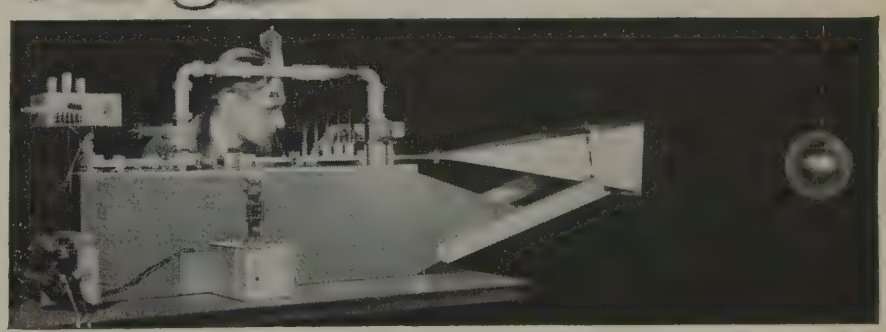
Laboratory measurement of radar cross-sections at microwave frequencies.



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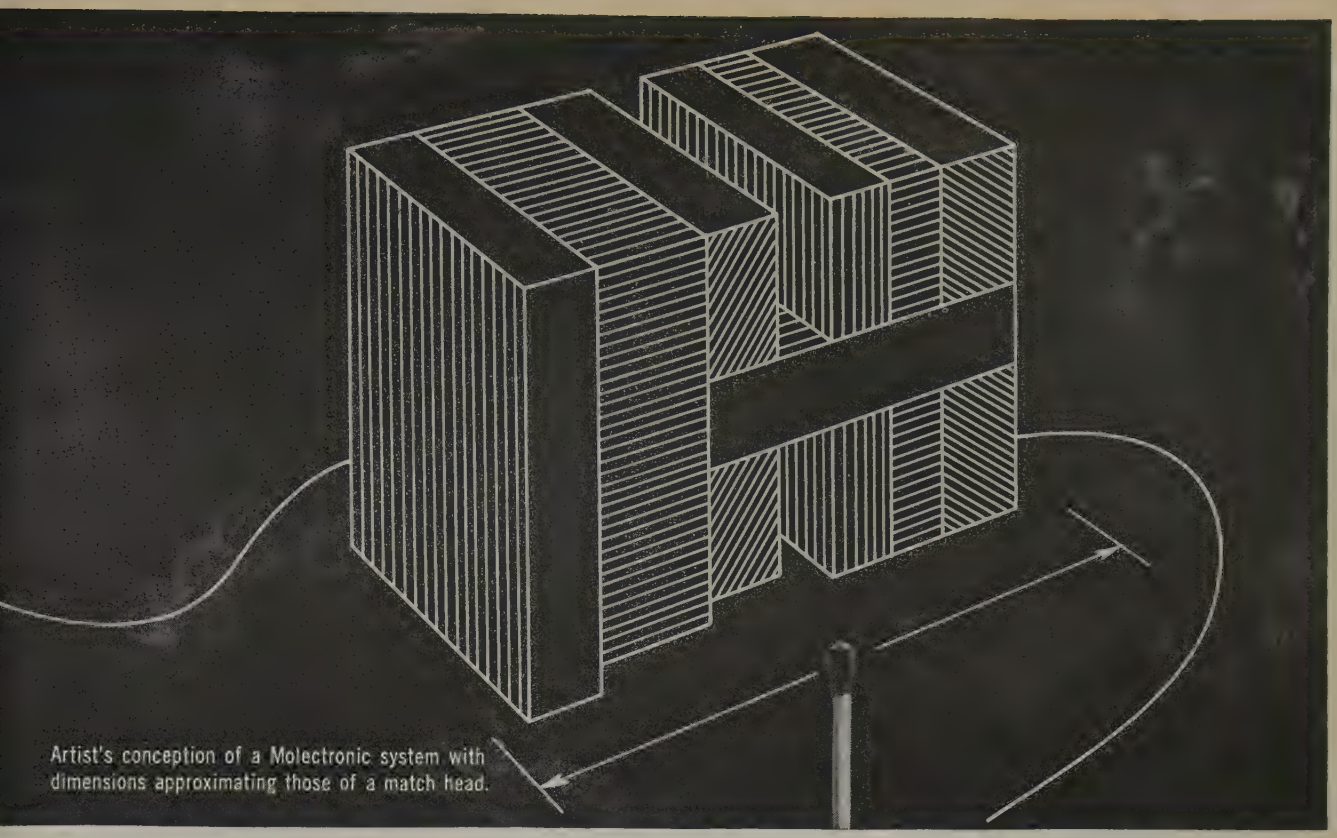

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Samwel, J. A., Wageningen, The Netherlands
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Schering, D. C., Amsterdam, Holland
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Schorr, F. W., Mountain View, Calif.
Schwartz, W. J., New York, N. Y.
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Smith, M. P., Ft. Huachuca, Ariz.
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(Continued on page 172A)

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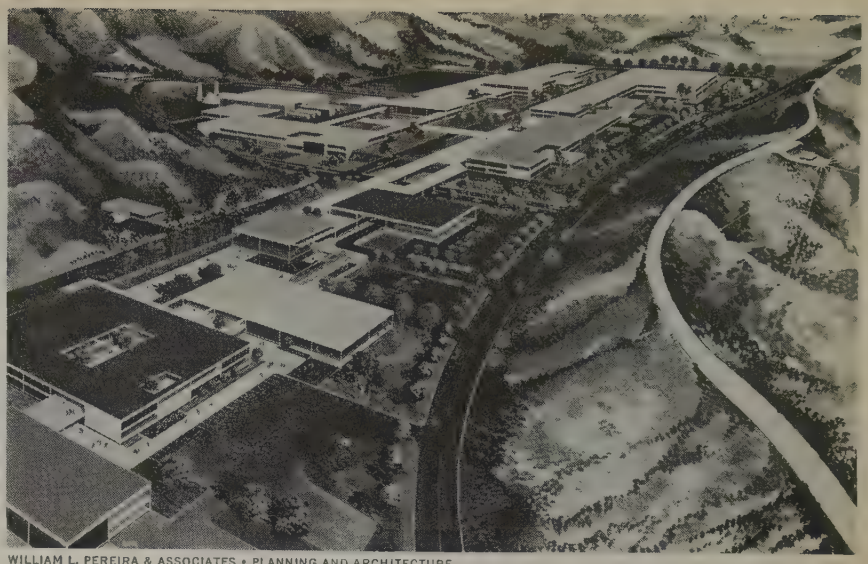

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Tiska, C. C., Fern Creek, Ky.
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Webster, A., Surrey, England
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Wiley, B., Whippany, N. J.
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Witcher, C. L., Winston-Salem, N. C.
Wolber, R. R., Amityville, N. Y.
Wolder, S., New York, N. Y.
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Wurdinger, E. D., Syracuse, N. Y.
Wythe, D. H., Jr., Monterey, Calif.
Yonezawa, S., Tokyo, Japan
Young, F. R., Erie, Pa.
Yovits, M. C., Washington, D. C.
Ziegelmair, L. A., Medford, L. I., N. Y.
Zonis, F. I., Cranbury, N. J.
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Zysman, B., New York, N. Y.

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Ashour, G. B., Silver Spring, Md.
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Bouse, G. B., Los Angeles, Calif.
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Burnett, N. C., Florissant, Mo.
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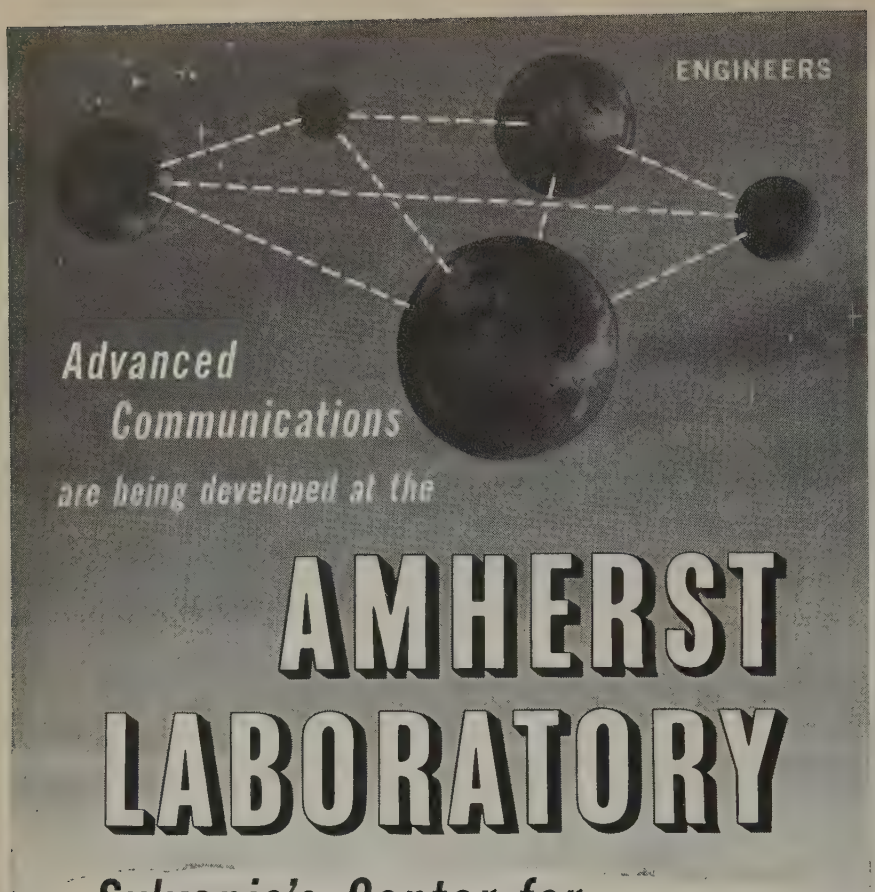

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Itsines, N. J., Topeka, Kans.
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Johnson, R. C., Decatur, Ill.
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(Continued on page 176A)

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Wernecke, H. W., Western Springs, Ill.
Wienski, S. E., Stamford, Conn.
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Williams, J. E., Indianapolis, Ind.
Wilson, D. S., Montreal, Que., Canada
Wilson, G. D., Orlando, Fla.
Wulff, J. J., Arlington, Va.
Yashir, A. A., Washington, D. C.
Zippel, G. A., Los Angeles, Calif.
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(Continued from page 6A)

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(Continued on page 178A)

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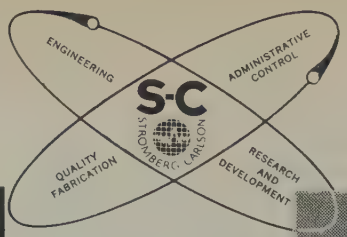

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Rochester, New York, home of Stromberg-Carlson, is a professional community of approximately 500,000, located in New York's famous upstate vacationland, noted for its cultural advantages: advanced study opportunities at the University of Rochester, the famed Eastman School of Music, the Symphony; unrivaled park and school systems, modern hospitals.

For additional information, please address your inquiry with an indication of your background to Mr. Fred E. Lee.

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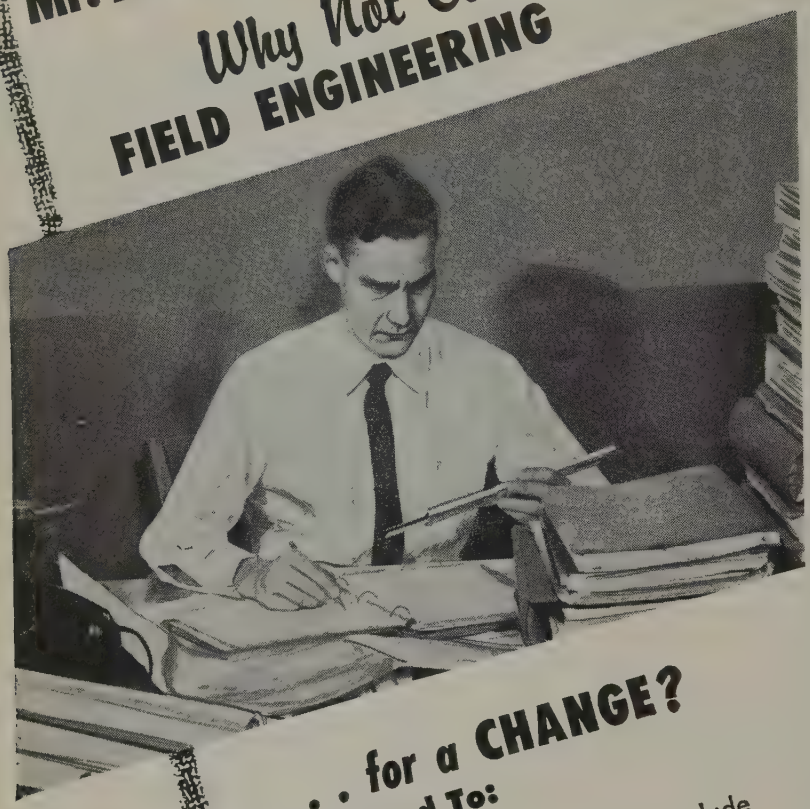

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Industrial Engineering Notes

(Continued from page 176A)

. . . The remarkable SOLION, the Navy's new electrochemical device that bids to replace the transistor in many electronic uses, is described in a Naval Ordnance Laboratory report just released for industry use by the Office of Technical Services, Commerce Department. The device is a product of a new technology developed by NOL called "chemistronics," which involves the movement of ions in solution. the uniqueness of the SOLION is the way in which its electrical charge is carried—by ions in solution rather than by electrons, as in the vacuum tube and transistor. According to the report, the Navy has devised five elemental types of SOLION units which can be combined in various arrangements to make specialized transducers, very low frequency amplifiers, long period oscillators, thresholding devices, clippers, integrators, and other devices. The most striking of the SOLION's characteristics is its extremely low power requirement, 100 to 1000 times less than that for transistors. It is also highly sensitive to low-energy stimuli. Other features are inherent stability, long life, simplicity of operation, light weight, and ease of manufacture. The illustrated volume is number PB 131931 and titled "SOLION: Principles of Electrochemistry and Low-Power Electrochemical Devices," and may be ordered from OTS, Commerce Department, Washington 25, D. C., at $1.25 per copy.

Engineering

A new international standard on Aluminum Electrolytic Capacitors for General Purpose Application has recently been announced by the U. S. National Committee of the International Electrotechnical Commission. The publication, identified as IEC Publication 103, is in general agreement with EIA Standard RS-154A on the same subject, and is available from the American Standards Association at $3.20 per copy. EIA's International Standards Committee, under Chairman Leon Pololsky of Sprague Electric, and Electrolytic Capacitor Committee, 34C, E. D. Martin, Magnavox Company, Chairman, were active participants in the formulation of this standard.

Military Electronics

The Army has said that radios as small as sugar cubes have been successfully developed using a completely new concept of micro-module circuits. The development, the Army announced, marks the beginning of the "cubist" era in electronics and is expected to play an increasingly important part in defense electronics. In this new scientific and engineering revolution, the vast range of jobs done by transistors and other electronic parts is being compressed into tiny micro-modules—circuit building blocks measuring only a

(Continued on page 180A)

ENGINEERS SCIENTISTS PHYSICISTS

Our client companies urgently need men for the below & many other positions. One interview can place your talents in the hands of a complete cross section of the Electronics & Missiles field. Our daily contact with engineering managers assures us of an insight to many forthcoming openings. Our special services are at your disposal with absolutely no charge to you. We are retained by the firms we represent.

SYSTEMS ANALYSTS

Original analysis in systems engineering as applied to advance communications, reconnaissance, data processing, air traffic control, electronic countermeasures or radar systems.

ENGINEERING MANAGER

Advance degree preferred to objectively lead a 100-man engineering design and research group in the field of communication and test equipment areas. Should have contributed to present association with patentable devices. Administrative ability must have been proven in past capacity.

RESEARCH PROJECT

Advance degree preferred. Will direct shock tube program and contribute to supersonic and hypersonic design. Will require liaison with advanced development groups and preparation of papers for symposiums.

PHYSICIST

Work with multi-division problems. Ascertain present product limitations and improve characteristics to surpass present specifications. Should have very broad background to present management with new theories in areas of instrumentation. Specialization in electromechanics.

CIRCUITRY DESIGN

The areas of digital and analogue computers require good creative background and transistor circuitry. At present we have approximately 426 positions for engineers experienced in IR, microwave, radar and communication systems.

GROUND HANDLING

Design and development of "Go-No Go" missile ground handling equipment. Background stronger in the electronic rather than the mechanical or structural design. Able to supervise technicians at missile test sites.

OUT OF STATE

We have clients in Ohio, Indiana, Florida, Massachusetts, New Jersey, New York interested in electronic engineers with two to ten years experience in specialized fields. Candidates are invited to inspect plant facilities and are made spot offers as soon as technical references are verified and relocation requirements are satisfied.

SALES ENGINEERS

Excellent opportunities currently exist for degreed engineers in sales and liaison to military, prime and sub-contractors in the below listed areas. Proven sales background or several years design of systems or circuitry with liaison contacts highly desirable.

ADVANCED OPENINGS IN THESE LISTED AND ASSOCIATED FIELDS EXIST WITH MANY OF OUR CLIENTS

Transistor Circuits	Solid State Physics
Digital Computers	Celestial Mechanics
Countermeasures	Servomechanisms
Semiconductors	Cosmic Ray Detection
Inertial Guidance	Long Range Radar

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Leonardo da Vinci

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Opportunities are now available at Melpar in the following areas

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  - Airborne Equipment
  - Ground Data Handling Equipment
  - Ground Support Equipment
- Simulation & Training Systems
- Communication & Navigation Systems
- Detection & Identification Systems
- Antenna & Radiation Systems
- Chemistry Laboratory
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* This quaint old proverb is one which we made up ourselves at least three weeks ago. Yet it's quite as true as though it had been uttered by an ancient Greek. If you'd like to contribute your talented efforts to the ever-expanding atomic weapons program, Bendix of Kansas City can offer you many kinds of rewards, including the financial, personal and professional. And we're really more up-to-date in Kansas City than the above illustration indicates, but, since we're a long term prime operating contractor for the AEC, you'll excuse us, we're sure, for not being more revealing about the nature of our work. You'll find us pleasantly specific, however, about the many real benefits we stand ready to offer capable electronics engineers with at least five years of experience in the activities listed at right. Openings exist at various levels. May we hear from you soon?

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- ELECTRONIC AUTOMATION
- MICRO-MINIATURIZATION
- MICROWAVE TECHNIQUES
- RELIABILITY
- VACUUM TUBE APPLICATION

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Kansas City, Missouri

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AVIATION CORPORATION
KANSAS CITY DIVISION

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Industrial Engineering Notes

(Continued from page 178A)

third of an inch on each side. Their small size can save critical space and weight in future satellite systems and rockets. By using the "disciplined geometry" of micromodules, electronic researchers already have achieved a better than ten to one size reduction over today's most refined equipment using printed wiring, transistors, and other small parts. In some cases, it was said, the reduction is 20 to one and further compression is considered feasible. Since the program was launched in April, 1958, tests by Army Signal Corps and RCA engineers show that the tiny cubes promise to be highly dependable, long-lived, use little power, deliver high performance, and greatly simplify repairs. They are extremely rugged due to their simplicity and monolithic shape.

Industry Marketing Data

Factory production of both radio and television receivers in February increased over January and over February, 1958. Cumulative output of both types of receivers increased appreciably over the like two-month period last year. Television production in February totaled 459,492 compared with 437,026 TVs made in January and 370,413 television receivers produced in February, 1958. The number of TVs made with UHF tuners totaled 34,678 compared with 35,841 in January and 34,048 TVs capable of receiving UHF signals made in February a year ago. Cumulative television output during the January-February period totaled 896,518 compared with 804,396 TVs made during the like two-month period last year. Radio receiver production in February totaled 1,125,385 including 432,551 automobile receivers, compared with 1,124,737 radios made in January including 420,052 auto sets and 876,891 radios made in February 1958 which included 268,445 automobile receivers. Cumulative radio receiver production during January and February of this year totaled 2,250,122 including 852,603 auto receivers compared with 1,739,177 radios made during the like 1958 months which included 618,124 automobile receivers. The number of FM radios produced in February totaled 29,145 compared with 30,235 made in January. Figures on FM radio output during the like 1958 period are not available. The cumulative total on the number of such radios produced during calendar year 1958 totaled 376,114. The last years upon which EIA has FM radio output figures are: 1955 when 252,880 such sets were made; 1954 when 188,685 FM radios were produced, and 1953 when 455,662 FM radios were made.

Use Your IRE DIRECTORY! It's Valuable!

It's great to be proud of the place you work

To some engineers, a job is a job is a job. But it doesn't have to be. It *can* be a career to take pride in, the way the engineers and scientists at Autonetics do.

These young men have already made Autonetics a leader in electronics and electromechanics. For example, they designed the inertial navigation systems for the USS Nautilus and Skate and the monopulse radar system for the Air Force's F-105.

These same young men now are working on new developments—an even more advanced inertial navigation system for the first nuclear-powered Polaris-carrying submarines... the guidance and control systems for the Minuteman and GAM-77 missiles... and many more.

Today at Autonetics there is room for engineers and scientists who want to have a part in these history-making activities. Please send your resume to Mr. G. F. Benning, 9150 East Imperial Highway, Downey, California.

Autonetics

A DIVISION OF NORTH AMERICAN AVIATION, INC.
Downey, California

INERTIAL NAVIGATION / ARMAMENT CONTROL / FLIGHT CONTROL / DATA PROCESSING

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For the advantages of our professional service, tailored to your needs, forward your résumé and a brief summary of the type of position you desire to David Cowin, Buttrick & Megary, Western Saving Fund Building, Philadelphia 7, Pa. Naturally this placement service involves no cost to you.

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 46A)

Delay Line

The new binary Delay Line Box offered by **Valor Instruments, Inc.**, 13214 Crenshaw Blvd., Gardena, Calif., is a lumped constant delay line which by the binary switching arrangement may be set to any delay to a precision of 0.8 per cent of the maximum value. The switching arrangement disconnects the unused portion of the delay line, thereby eliminating the bothersome reflections associated with variable delay lines. These units may be used in laboratory instrumentation or as a substitute delay line component. Seven different models are available providing delays up to 12.6 microseconds, impedances of 100 and 500 ohms, and rise time values of 0.3, 0.1 and 0.05 microseconds. The delay lines which make up these boxes are precision, highly stable, lumped constant delay lines using powdered iron toroidal inductors and temperature compensating capacitors.

Compact Display Tube

A new nine-pin display tube (7AUP4) designed for airborne and monitor applications is now available from the **Westinghouse Electric Corp.**, P.O. Box 284, Elmira, N. Y.

The seven inch-diameter tube features a $\frac{7}{8}$-inch diameter neck for decreased deflection power. The over-all length of the tube is 88 inches and is of the electrostatic focus, magnetic-deflection type. Deflection angle is 70 degrees.

The new tube has a P-4 phosphor and a metal-backed screen and can be furnished with a potted anode lead.

(Continued on page 184A)

an

invitation to the CREATIVE engineer!

HRB invites you to become part of a team of R and D specialists. The company offers opportunity for electronic research, development and design in a wide range of projects. The talented person may assume full responsibility on a given job. Those with initiative and imagination may broaden their scientific know-how in a professional environment. Liberal company benefits, promotions based on merit, and the opportunity for company-paid graduate study at neighboring Pennsylvania State University are some of the many advantages at HRB.

Openings in:

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HRB PERSONNEL DIRECTOR

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Science Park, State College, Pa.
A Division of
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SYSTEMS ENGINEERS

...to work in advance areas of Systems Planning, Development and Design for Missile Detection on a Global Scale

These positions are with the Missile Detection Systems Section of General Electric and require high technical and creative capacities. All assignments offer fruitful opportunities to make state-of-the-art advances with an organization that encourages and rewards the individual contributor. The ability to function both through individual action and team leadership is highly valued. Current openings are in these areas:

ADVANCED RADAR SYSTEMS PLANNING

Work in this area calls for engineers able to visualize and define future defense and space problems and conceive advanced radar systems to solve them.

RADAR SYSTEMS ANALYSIS & DEVELOPMENT

An advanced degree and/or strong background in systems analysis and design is essential for such assignments as:

...analyze and define requirements for advance detection systems and determine broader parameters for such systems; establish their feasibility.

...analyze long range missile detection systems and specify optimum configuration on the basis of utility, performance, cost and delivery.

SPECIALISTS IN ELECTRO-MAGNETIC PROPAGATION

PhD or MS is required in this area. Scientists will carry out analysis of propagation phenomena, as related to long range missile detection. Plan detailed investigations and illustrate practicability of results. Ability to assume responsibility essential.

OPPORTUNITIES IN D & D OF RECONNAISSANCE RECEIVER DESIGN & SYSTEMS EQUIPMENT

Assignments require specialized background in one or more of these areas: VHF and UHF frequency spectra (P & L bands) • ECM • Microwave; wave guide components, Duplexers, switches, hybrids; VHF and UHF transmitters.

ALSO POSITIONS IN COMPUTER APPLICATIONS

(Knowledge of large business or special purpose computers needed) and COMPUTER PROGRAMMING (experience with IBM 704 & 709 needed.)

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Missile Detection Systems Section
HEAVY MILITARY ELECTRONICS DEPT.

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MINORITY CARRIER LIFETIME
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Provides a reproducible measure of minority carrier lifetime of both germanium and silicon samples. Measurement evaluates performance characteristics to be expected of devices made from the sample material.
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Precious Metal Wires for Potentiometers and Resistance Thermometers.

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NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

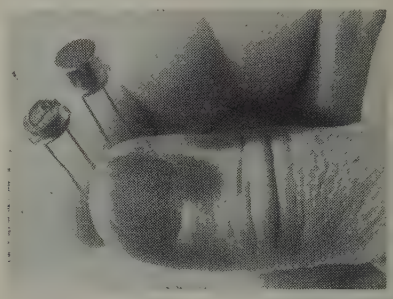
(Continued from page 182A)

The normal operating characteristics of the 7AUP4 are as follows: anode voltage, 800 volts; grid number 2 voltage, 300 volts; focus voltage, 0 to plus 300 volts; cutoff voltage, 25 to 75 volts; highlight brightness, 75 foot-lamberts minute; spot size, approximately 0.010 inches.

For further information, write to Westinghouse.

Silicon Diode Switch

A higher power 4-layer diode designated as Type AD has been announced by the **Shockley Transistor Corp.,** Stanford Industrial Park, Palo Alto, Calif., a subsidiary of Beckman Instruments, Inc. This new self-actuated silicon switch is similar in function to a relay or gas tube. It is turned on by a voltage pulse, turned off by dropping the current or reversing the voltage. To match circuit requirements, it is available with switching of 30, 40, 50 and 200 volts and holding currents of 5 to 45 ma.



Compact and rugged, the Type AD is capable of handling 300 ma steady dc or a 20-ampere pulse current. A string of four in series will switch 800 volts, resulting in peak power of 16 kw, allowing use in magnetron pulsing, radar beacons and other modulator applications.

Type AD is available in production quantities for pulse generator circuits, detonator firing circuits, dc to dc power conversion and other applications usually requiring thyratrons or relays.

Electrometer

A new log electrometer for precision measurement of small currents over a wide dynamic range is announced by **The Victoreen Instrument Co.,** 5806 Hough Ave., Cleveland 6, Ohio.

(Continued on page 186A)

When you must have recording range out to 150 cps . . . immediately visible, permanent traces in rectangular coordinates . . . a large number of channels in the limited space of a mobile van or control room . . . and the flexibility of a variety of economical preamps—a Sanborn 850 system is the *one* most practical answer to *all* these requirements. In aircraft and missile telemetering facilities, computer installations, test stand work and similar multichannel recording applications, the "850" is proving its unique adaptability and practicality.

You can unplug and change "850" preamplifiers in seconds to record a wide range of variables. Select by pushbutton any of nine electrically-controlled chart speeds from 0.25 mm to 100/sec. Observe and make notes on the convenient 8" vertical chart display. Reload charts quickly and easily from the front. Every operating feature *you want* is backed up by the performance specifications *you need*—for the greatest possible recording usefulness.

DC Coupling and Phase Sensitive Demodulator preamplifiers are now available. Carrier and Basic Chopper preamplifiers are now being prepared for production. A rack-mounted Master Oscillator Power Amplifier (MOPA) to supply Carrier and Chopper excitation is also in preparation.

THE ONLY 6- or 8-CHANNEL DIRECT WRITER

THAT OFFERS YOU

Response to 150 cps
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ECONOMICAL PREAMPS

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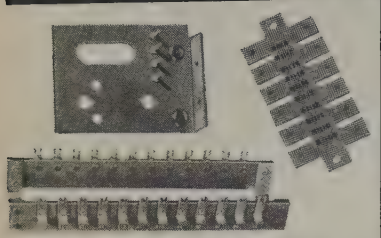

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NATIONAL TEL-TRONICS CORPORATION
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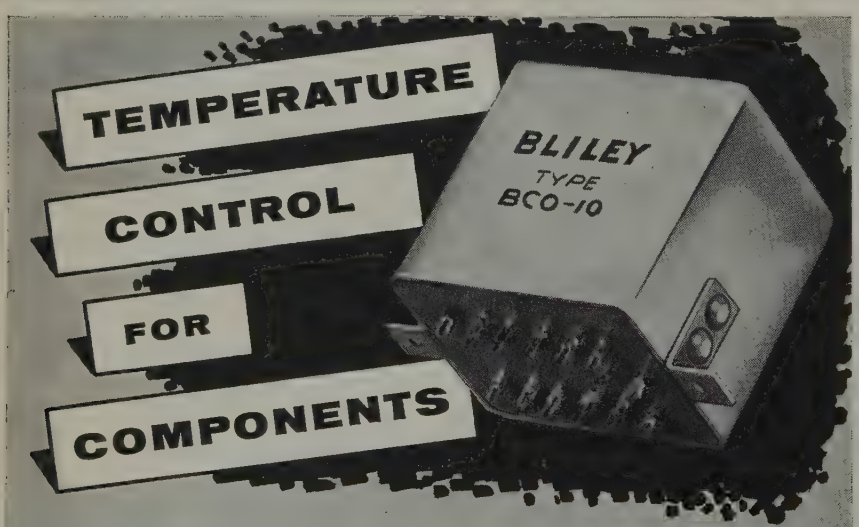
TEMPERATURE CONTROL FOR COMPONENTS



For temperature stabilization of diodes, the new Bliley BCO-10 oven will hold ±1°C with ambient temperature variation from −10°C to +50°C. Stability is better than ±4°C from −55°C to +70°C.

Compact unit has multiple contacts (20 terminals) for mounting up to 10 diodes. Dimensions, less brackets, are $1\frac{15}{32}$" x $1\frac{3}{4}$" x $1\frac{29}{32}$". Design features an hermetically sealed snap-action thermostat and non inductive heater winding to minimize noise and interference in low level circuitry.

Standard models are available for operation at 50°C or 75°C with 12.6 volt, 26.5 volt or 115 volt heaters as required.

Request Bulletin 517 for Complete Information.

Bliley
BLILEY ELECTRIC COMPANY
UNION STATION BUILDING • ERIE, PENNSYLVANIA

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 184A)

Designated as Model LE-1 Log Electrometer, the equipment is in production and available for short-term delivery.

Designed by Tullamore Electronics, new subsidiary of Victoreen, the Model LE-1 Log Electrometer is particularly well suited for use as a reactor control instrument. It can be rack, panel or console mounted.

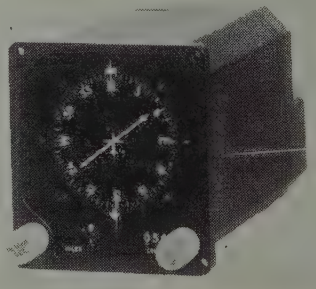
The manufacturer states that the Model LE-1, in addition to being stable and reliable, provides an inexpensive method of measuring 8 decades of current in the range of 10^{-5} to 10^{-13} amperes. Trip circuits can be incorporated on special order.

Logarithmic measurement of current is obtained by utilizing the log characteristic of screen-feed back to the input of the electrometer tube, which eliminates the necessity for a separate diode device. The CK 5886 electrometer tube uses an extremely low input grid current. DC operation of the tube filament from a double regulated supply provides excellent stability.

Full specification data on the Victoreen Model LE-1 Log Electrometer is available on request to the firm.

Horizontal Situation Indicator

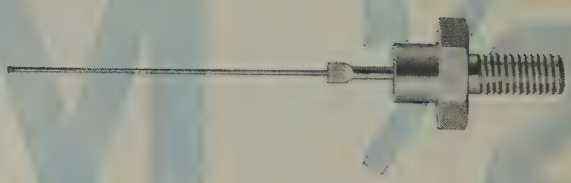
A research and development program based on a course line indicator concept developed by **Collins Radio Co.**, Cedar Rapids, Iowa, has resulted in a new Horizontal Situation Indicator (HSI) now being used by the Air Force in their new Integrated Instrument Panels. The HSI presents a horizontal or plan view of the aircraft with respect to the entire navigation situation.

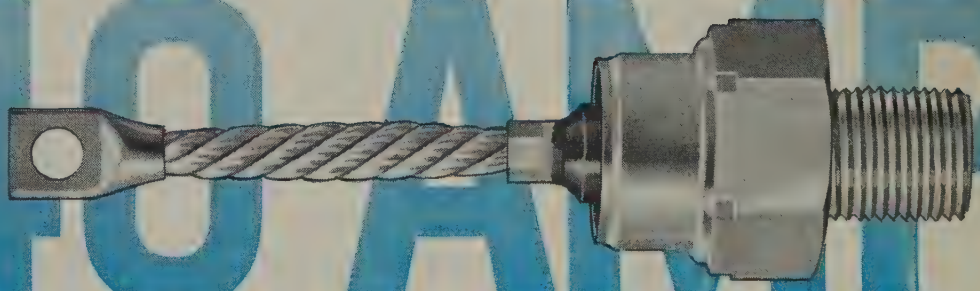


The development of the Integrated Instrument Panel was sponsored by the Flight Control Laboratory of Wright Air Development Center. It is designed for all-weather monitoring and control of high performance aircraft and provides a complete flight director steering and navigation situation on two 5 inch instruments in the center of the panel. Bracketing these instruments are two vertical scale indicators providing aircraft performance and mission requirement data.

(Continued on page 188A)

FROM ½ AMP TO 240 AMP





Westinghouse offers the industry's most complete line of silicon rectifiers!

Look to the leader next time you require a quality-built, performance-proved silicon rectifier of any size or power-handling capacity. Westinghouse offers the industry's largest selection, from TV diodes to high-power 240 amp. rectifiers for all types of power applications. All diodes and rectifiers use high-purity silicon for high temperature operation, long life, *and* high efficiency. We can supply all standard configurations, or build to specification. Special devices, such as bridges in series or parallel, can be supplied on order. And since most products are in stock, we guarantee quick delivery.

Transistor users note: Westinghouse can also supply a large selection of silicon power transistors, germanium transistors, as well as special semiconductor products.

For complete technical data, call your Westinghouse Sales Representative.

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the most versatile...most sensitive direct writing recorder available!

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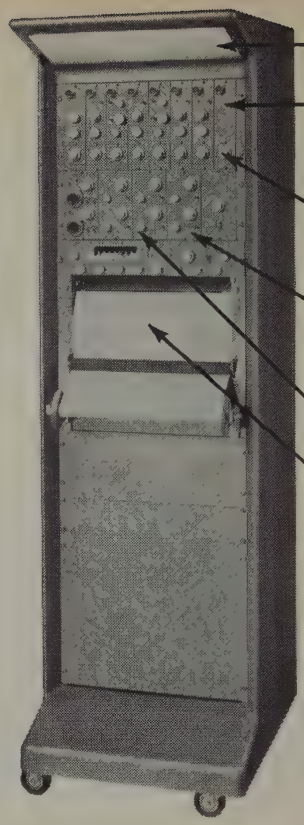
TYPE R DYNOGRAPH

Whatever your application for direct writing records . . . investigate the ability of the Offner Type R Dynograph to do the job *better* and more *simply*. Its features of superiority are unmatched!

- *stable d-c sensitivity of one microvolt per mm*
- *true differential input*
- *high input impedance*
- *response to beyond 150 cps*
- *reluctance, differential transformer, strain gages with a-c or d-c excitation, thermocouples, etc., used with all preamplifiers*
- *deflection time less than 1.5 milliseconds (2.5 ms with preamplifiers)*
- *fixed precision calibration*
- *instant warm-up*
- *precision source for d-c and 400 cycle excitation, self-contained*
- *zero suppression, twenty times full scale, both directions*



Illuminated canopy.

Type 9800 series input couplers provide all input, control and balance functions.

Type 481 Preamplifier provides sensitivities from one microvolt to 5 volts per mm.

Type 482 power amplifiers—may be used without preamplifiers for up to 10 mv/cm sensitivity.

Zero suppression control.

504-A paper drive—speeds from 1 to 250 mm/sec. Electrical speed shift 1 to 250 mm per minute available. Zero weave high precision drive, 850 ft. capacity (heat or electric) 1500 ft. (ink). Front loading, with full unobstructed record visible from front.

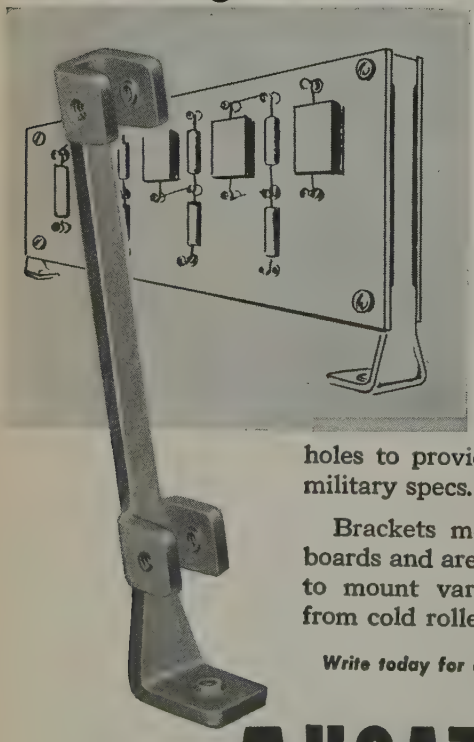
OTHER MODELS AVAILABLE

1 to 19 channels, console, rack, and portable assemblies.

OFFNER ELECTRONICS INC.
3912 River Road, Schiller Park, Ill. (Suburb of Chicago)

Write on your company letterhead for details and specifications.

New Augat Panel Mounting Brackets



offer unique extruded-thread feature

Newest addition to the Augat line, these panel mounting brackets provide rigid support for vertically-mounted component boards under shock and vibration. The special feature of this bracket is five extruded holes to provide four full threads, meeting military specs.

Brackets mount either single or double boards and are available in different heights to mount various size panels. Fabricated from cold rolled steel, cadmium plated.

Write today for additional information and samples.

AUGAT BROS. INC.
31 PERRY AVENUE • ATTLEBORO, MASS.

NEWS New Products

(Continued from page 186A)

Navigational information on the HSI includes a combination of heading, course, bearing, and distance information formerly displayed on a variety of instruments or not previously available to the pilot. The instrument can be used in conjunction with inputs from ADF, AGCA, AGCI, TACAN, VOR, ILS and Data Link, and it has the capability for use with Doppler radar and other navigation systems now under development. It provides for tie-in with various flight director and automatic pilot systems.

The pictorial presentation of the HSI provides easily interpreted aircraft heading; selected heading; heading error angle; the bearing and distance to a radio facility; destination, target or computed waypoint; the navigational or computed course and course deviation; the direction of travel along the course and the mode of operation being displayed.

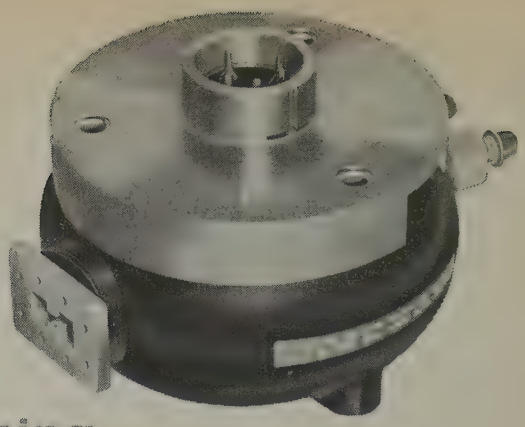
Low Noise Preamplifier

A new UHF preamplifier with a noise figure of 4–5 db and a 20 db gain at an operating frequency of 400–500 mc has been added to the preamplifier line of **Rixon Electronics, Inc.**, 2414 Reedie Drive, Silver Spring, Md. The new model, AP-

(Continued on page 190A)

SMALLEST LIGHTEST CARCINOTRONS

with wide band sole tuning



Though it has just recently made its debut into the high society of Litton microwave tubes, this M-Type carcinotron (our model L-3298) has already been commended by the military for its exceptionally clean design. Every engineer concerned with upgrading the performance of ECM equipment will surely find much of interest in this medium-power tube, with which Litton takes a major stride toward truly simultaneous noise-jamming capability by affording faster tuning rates than any previously attainable.

The Litton family of eight electrically-compatible carcinotrons is the first to incorporate the critical capability of wide band sole tuning without frequency or power holes when the tube is operated into as much as a 2-to-1 mismatch. Litton carcinotrons are the first to use wider-than-normal-band RF output couplers, minimizing many system components such as antennae, waveguide plumbing, and load isolators.

We cite these firsts not for glory's sake, but rather for their meaningful contribution to more efficient system design, smaller size and lighter weight.

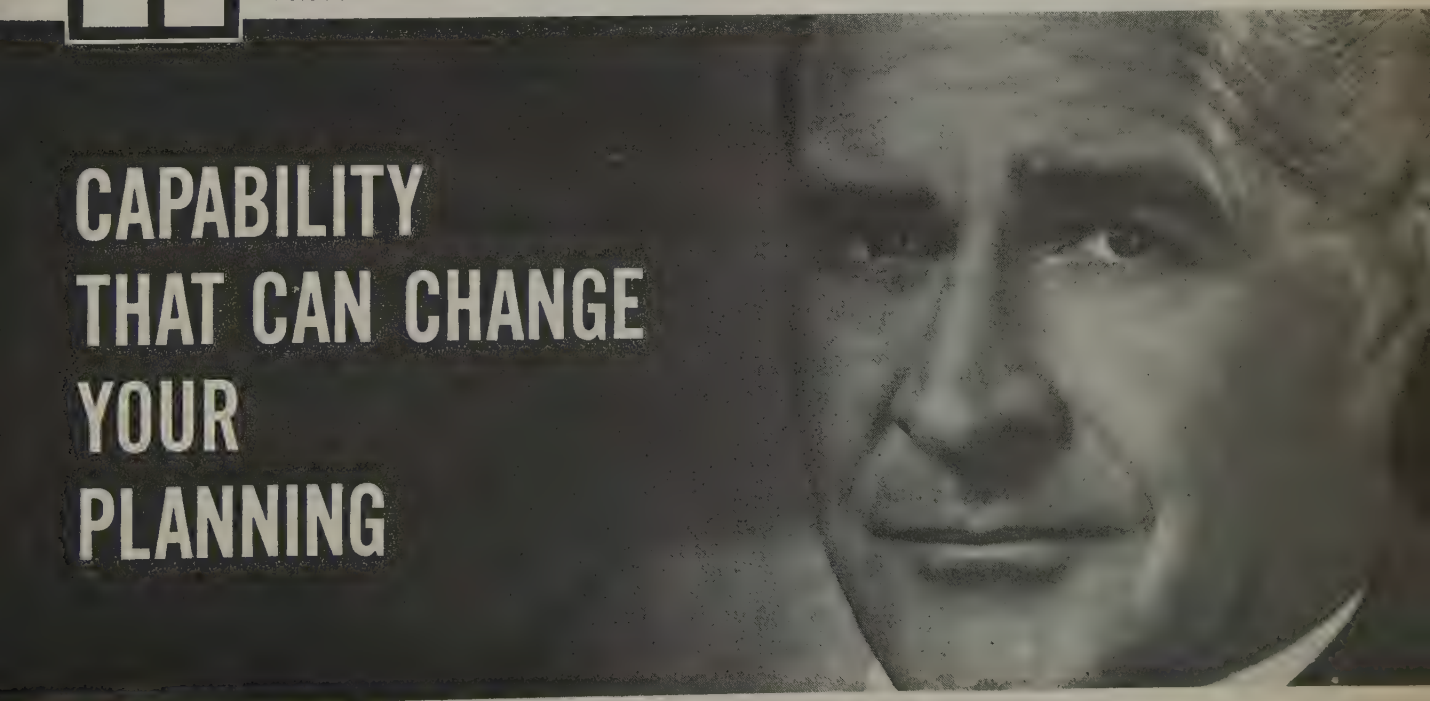
The notable suitability of these carcinotrons is not limited to ECM. You can also consider them for other military applications such as drivers for communications links—in fact, wherever medium-power tubes with extremely rapid tuning and low tuning power are required. And while you are considering, remember: these versatile tubes are not just drawing-board products—you can order them now.

Feel free to lodge your inquiry about voltage-tuned power oscillators of whatever nature with us at Litton Industries Electron Tube Division, Office P6, 960 Industrial Road, San Carlos, California. Your request for our newest catalog or for answers to your specific questions will be honored promptly.

LITTON INDUSTRIES Electron Tube Division

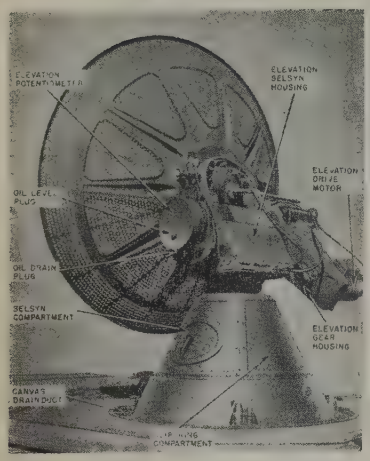
MAGNETRONS • KLYSTRONS • CARCINOTRONS • TRAVELING WAVE TUBES • BACKWARD WAVE OSCILLATORS • GAS DISCHARGE TUBES
NOISE SOURCES • SPECIAL ECM TUBES • CROSSED-FIELD AMPLIFIERS • MICROWAVE FILTERS • DUPLEXERS • TR TUBES

CAPABILITY THAT CAN CHANGE YOUR PLANNING



RADIO RESEARCH INSTRUMENT CO.

550 FIFTH AVE. NEW YORK JUDSON 6-4691



ANTENNA PEDESTAL SCR 584—MP 61B

Full azimuth and elevation sweeps, 360 degrees in azimuth, 210 degrees in elevation. Accurate to 1 mil. over system. Complete for full tracking response. Includes pedestal drives, selsyns, potentiometers, drive motors, control amplidynes. Excellent used condition. This is the first time these pedestals have been available for purchase. Limited quantity in stock for immediate shipment. Ideal for antenna pattern ranges, radar systems, radio astronomy, any project requiring Complete description in McGraw-Hill Radiation accurate response in elevation and azimuth.

Laboratory Series, Volume 1, page 284 and page 209, and Volume 26, page 233.

AUTOMATIC TRACKING RADAR

Complete system for missile, aircraft, satelite, balloon tracking to altitude of 100 miles or better. Housed in own van 20 ft. x 12 ft. x 8 ft. As new. Write us.

2 MEGAWATT PULSER

Supplies 2 megawatt to magnetron at a pulse duration of 2 microsec. Fixed gap type. Uses 4C35 hydrogen thyratron. Brand new complete. G.E. $1150.00.

F-28/APN-19 FILTER CAVITY

Jan. spec: Tuneable 2700-2900mc, 1.5db max. loss at ctr freq over band. Details: Insertion loss variable. Single tuned filter for freq channelling in radar beacon. Invar center tuning conductor ¾ wavelength. New $37.50 each.

⅞" RIGID COAX. RG44/U 50 ohm, standard fittings, 10cm stub supported. 12 ft. lengths. Silver plated. New $34.50 each. 12 ft. length. Right angle bends $6 ea.

AN/CPN-6 X-BAND BEACON

Complete beacon installation including spares and antennas $1500 each. New.

TOPWALL HYBRID JUNCTION. 8500-9600mc 1x.5 wg size. Broad banded better than 16%. Aluminum casting, 015.00 new. Crossover output, 1x.5 wg size. $5.00 new.
BROAD BAND BAL MIXER using short slot-hybrid. Pound type broad band dual balanced crystal holder. 1x.5 wg size. $25.00 new.

VD-2 PPI REPEATER

Takes any radar PPI info and displays on 7" tube compact floor standing console. Complete rotating yoke assy. 115V 60CY AC Pwr. 4, 20, 80, 200 mile ranges. Brand new w/Inst. Bk. $385.

AN/APS-10 3CM. X BAND RADAR

Complete RF head including transmitter, receiver, modulator. Uses 2J42 magnetron. Fully described in MIT Rad. Lab. Series Vol. I, pps. 616-625 and Vol. II, pps. 171-185. $375.00. Complete X band radar system also avail. incl. 360 deg. antenna, PPI, sync, pwr supply. Similar to $17,000 weather radar now in use by airlines. $750 complete.

INTRODUCING THE **NEW**

Belleville-Hexem MODEL 110A

E-I-R METER for your DC Measurements

E • 1 millivolt to 1000 volts full scale in 13 ranges, 101 megohms input resistance, ±2% accuracy

I • 1 millimicroampere to 300 milliampere full scale in 18 ranges, 100 millivolt voltage drop, ±2% accuracy

R • 10 ohms to 100 megohms center scale in 8 ranges, ±5% accuracy

PRICE: $315, STANDARD; $350, RACK

Your B-H engineering representative will be happy to arrange a demonstration. For his name and complete technical data, write The Belleville-Hexem Corporation, 638 University Avenue, Los Gatos, California.

crimp-type, snap-locked contacts

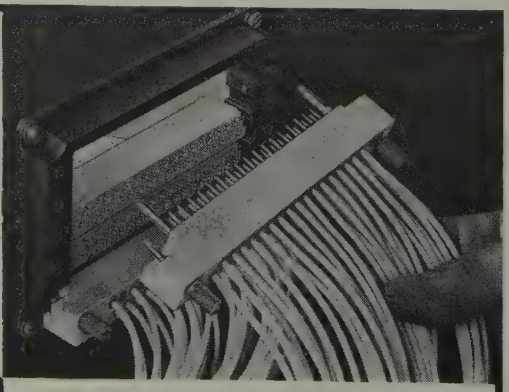
Modular

HYFEN®

connector

feed-thru, multiple insert

Makes possible the design of lighter and more compact equipment. Each insert holds 35 contacts. Frames available for 5 or 8 inserts.



BURNDY

For complete information, write: OMATON DIVISION, BURNDY—Norwalk, Connect.

59-1

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 188A)

710-1, is designed to operate with a 40-ohm source and load impedance. According to the manufacturer, the unit makes a major improvement when placed in front of an average commercial receiver. To achieve the same communications improvement, without the Model AP-710-1 preamplifier, transmitter power would have to be increased four times.

The unit uses two of the new MIL-type GE subminiature ceramic planar triodes (type 7077) in a two-stage grounded-grid configuration. The small dimensions of the 7077 permit its mounting as an integral part of the rigid coaxial type cavity resonators resulting in a very compact amplifier package (19×3½ inches) that includes a self-contained power supply.

Tuning is accomplished with a simple screw-driver type adjustment provided by each of the rigid coaxial cavities. Also an internal adjustment permits optimizing the noise figure to less than 5 db at a frequency within the 400–500 mc range.

Other models are available on short notice that cover any band in the 10–500 mc range.

Silicon Rectifiers

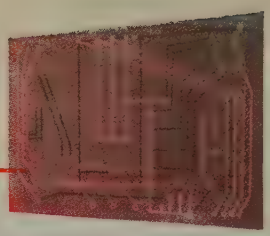
Transitron Electronic Corp., Wakefield, Mass., announces military approval of a series of axial lead silicon rectifiers. These components, already in manufacture, add to a growing list of Transitron semiconductor products meeting military specifications.

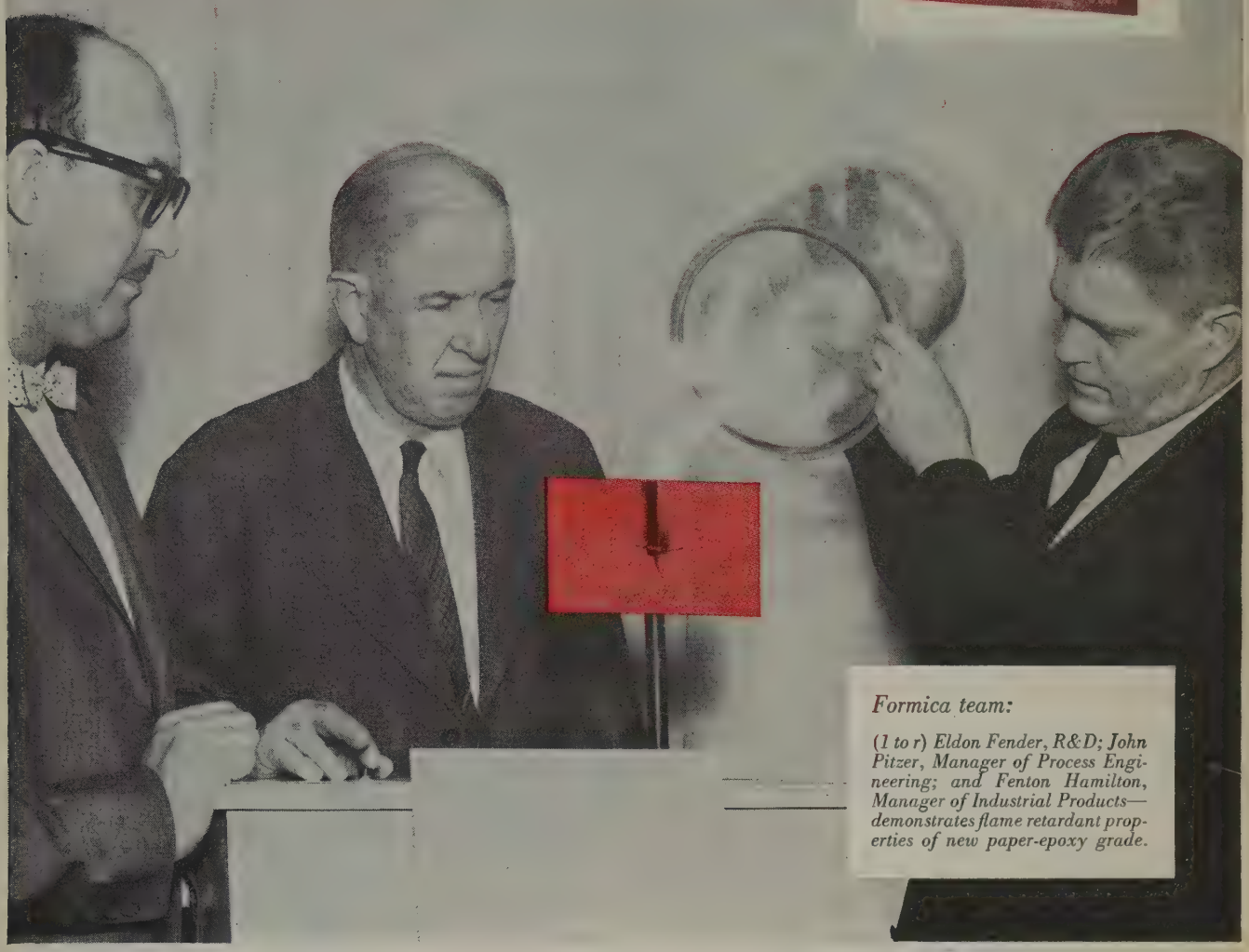
These JAN silicon rectifiers are designed for use in applications that demand reliable operation at high temperatures and under severe environmental conditions. Trnasitron JAN types 1N538, 1N540, and 1N547 offer high efficiency and ease of mounting in new and existing rectifier applications. Maximum ratings are 200, 400 and 600 volts respectively at 250 milliamperes, 150°C ambient temperature.

(Continued on page 192A)

FORMICA® Laminated Plastic

NEW EP-37





Formica team:

(1 to r) Eldon Fender, R&D; John Pitzer, Manager of Process Engineering; and Fenton Hamilton, Manager of Industrial Products—demonstrates flame retardant properties of new paper-epoxy grade.

Formica perfects new Flame Retardant grade

New EP-37 Properties . . .

- Flame retardant
- Self-extinguishing
- Dimensional stability under both solder dipping and humidity conditions
- Million megohms IR
- Cold punch 1/16"
- 10# avg. bond strength
- 500°F. solder heat resistance for 25 secs.

The team shown above demonstrates the flame retardant, self-extinguishing properties of the newest Formica® copper clad, EP-37. Because of these unusually effective properties, the new paper-epoxy is well suited for use in computers, radio, tv, telephone and aviation electrical devices. Increased dimensional stability—30% greater than existing grades under moisture conditions—offers many other application advantages.

This basic new material offers the additional properties shown at left—so essential for dependable printed circuit performance. For complete information, send for free test sample and data information. Formica Corporation, a subsidiary of American Cyanamid, 4532 Spring Grove Ave., Cincinnati 32, Ohio.

FORMICA Laminated Plastic

a product of CYANAMID

FI-2158

YOU CAN HAVE_____

HIGH SPEED SIGNALLING PLUS RUGGEDNESS AND RELIABILITY WITH

RIXON'S NEW SEMICONDUCTOR RELAYS

MODEL SCR-60
(Cover Removed)

IMPORTANT FEATURES:

- No mechanical inertia to limit speed.
- No mechanical parts to break or wear out.
- Unaffected by dirt.
- Direct replacement for mechanical relays (WE 255A etc.).
- Resistant to vibration and shock.

CONDENSED SPECIFICATIONS

MODEL SCR-60

Operating Speed—2500 Baud (bits/second)
Input Coil Safe Working Voltage to Ground--300
Output Contact Safe Working Voltage to Ground --300
Input Current--10 to 80 ma max.; 20 to 60 nominal
Input Resistance—135 ohms
Maximum Open Circuit Voltage per Dual "Contact" unit--150
Maximum Safe "Contact" current--200 ma
Closed Circuit Voltage Drop per "Contact"—Less than one volt
Available Input Coil Arrangements—Polar, Neut., 2 Independent Chans. or Biased Neut.
Available Output "Contact" Arrangements—
Polarized
1. Polar (C) ±75 volts.
2. 1 Neutral (A) 300 volts.
3. 1 Neutral (B) 300 volts.
4. 2 Neutral (A) 150 volts.
5. 2 Neutral (B) 150 volts.
6. 1 Neut. (A) 150v and 1 Neut. (B) 150v

Nonpolarized: 1 Neut. (A) 150v or 1 Neut. (B) 150v.
Mechanical—Base—Same as WE 255 A
Size—Base 2 11/16 × 2 11/16 in.
Height over-all—5 11/16 in. including mounting feet
Height Above Base—4½ in.

The Model SCR-60 is just an example of one of Rixon's new line of semiconductor relays. They can be custom-designed to meet any customer's specifications. The new line has good safety margins for use in signalling circuits up to 300 volts d-c. They use power transistors whose input circuits are independently isolated from each other. This circuit isolation allows a variety of series or parallel connections. Protective circuits are incorporated to prevent accidental burnout from overvoltage or misconnection. Write or phone for technical literature, prices, and delivery time.

RIXON ELECTRONICS, INC.
2414 Reedie Dr., Silver Spring, Md. • LO5-4578

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* *Buckbee Mears Company also manufactures etched forms and electroforms of unusual accuracy—items used in electronic tubes, shaver heads, numerical indicator tubes, color television masks. Perhaps a component for your product could be made better and more economically by this process. We will gladly quote from your specifications.*

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CA 7-6371

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

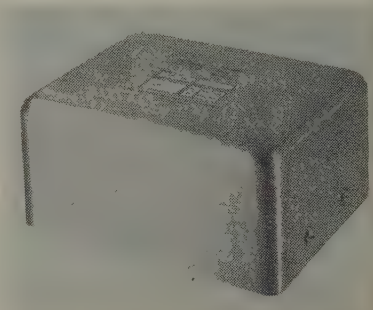
(Continued from page 190A)

Dual Photocell Amplifier

This new T878 dual photocell amplifier is a standard panel mounted unit, used for converting photocell phase sensitive signals to momentary relay on-off signals. Manufacturer is **Sterling Precision Corp.**, 17 Matinecock Ave., Port Washington, N. Y.

Transistorized Power Supply

Southwestern Industrial Electronics Co., 10201 Westheimer, Houston, Texas, a Division of Dresser Industries, Inc., announces the introduction of its TPC-15 Transistorized Power Supply. The unit is specifically designed for airborne use. It features a bridge-transistor circuit using low-voltage transistors to deliver 300 volts dc at 150 ma, or 150 volts dc at 300 ma from the aircraft 28 volt battery source. Regulation is better than 5 per cent over the entire output range—no load to full load—and efficiency is better than 85 per cent. Output is virtually free from ripple and noise.

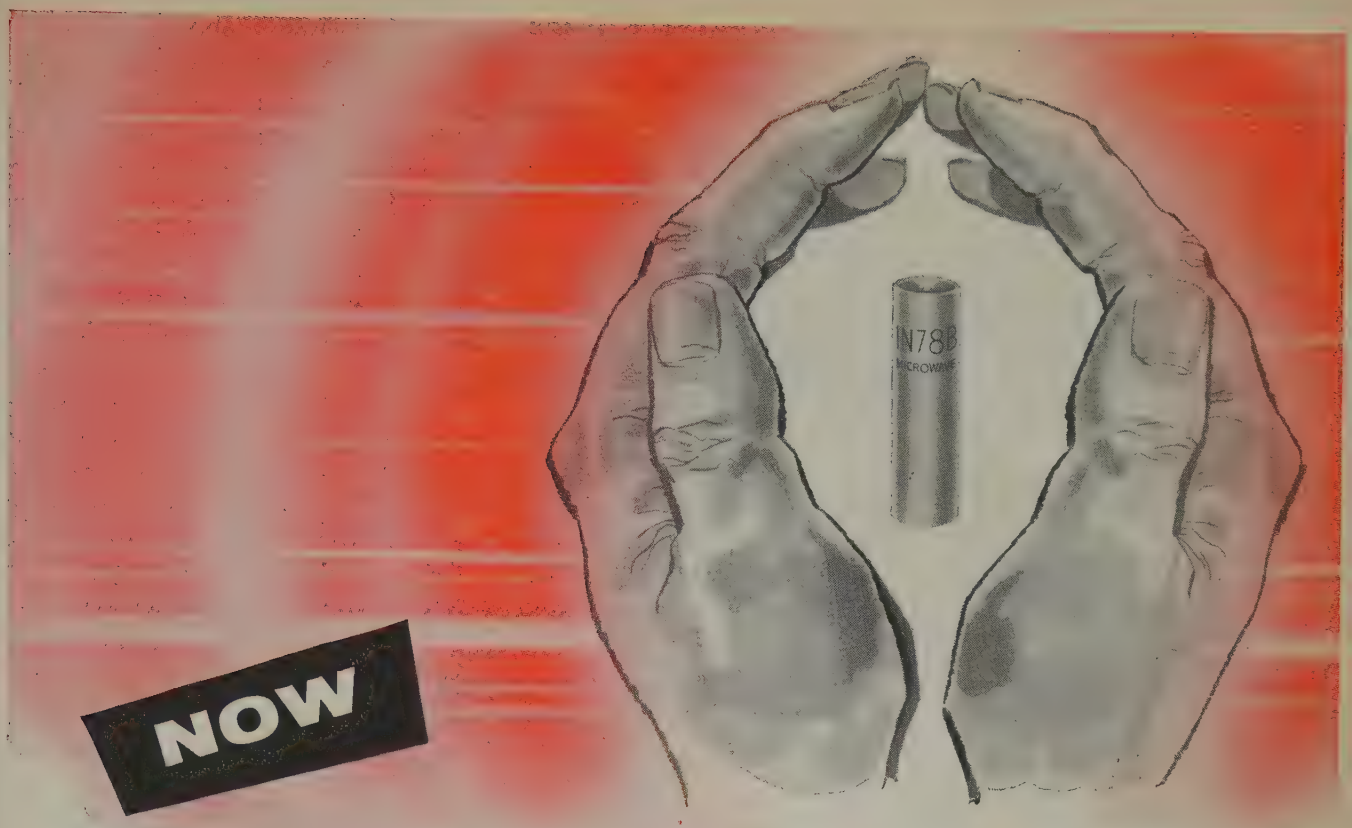


The TPC-15 is mounted on an aluminum chassis and has a clear-anodized aluminum cover which is quickly detachable to offer complete accessibility. The unit is stressed to withstand the shock and vibration of the airborne environment over a −40 to +65°C temperature range. It offers the compactness, reliability and light weight needed for airborne applications as a replacement for conventional dynamotor power supplies.

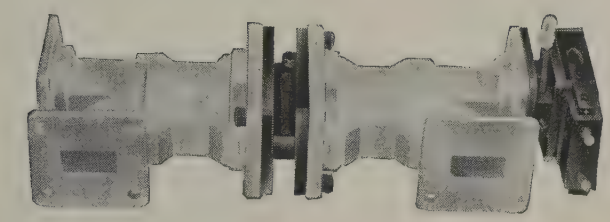
Computer Brochure

Describing off-line processing of data to permit full utilization of computers and data processing systems, a new six-page brochure, "Computer Language Translator for Data Processing Systems," is now

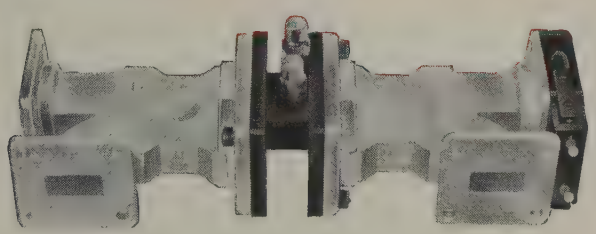
(Continued on page 194A)



Guaranteed protection in Ku band!



BALANCED DUPLEXER: DUAL PRE-TR, DIODE PROTECTOR, SHUTTER



BALANCED DUPLEXER: DUAL TR, SHUTTER

FERRITE DUPLEXER: DIODE PROTECTOR, SHUTTER

New Microwave Associates Ku Band duplexers give you guaranteed crystal protection - for life - at full rated power and elevated temperatures.

For the first time, Ku Band users are enjoying crystal protection never before attained in this band!

New, highly successful gas tube and ferrite devices of proven design but previously produced for L, S & X bands, are now in actual production for Ku Band . . . and available for immediate delivery.

These new duplexers developed by Microwave's Switching Devices Laboratory under the direction of Dr. Lawrence Gould are guaranteed to solve premature crystal burnout problems. One of these systems will bring you optimum duplexer performance and reliability. All three use the MA-760 shutter for standby receiver protection.

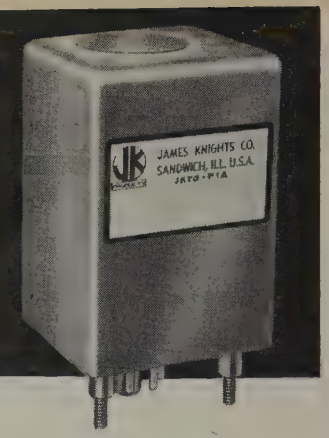
If you work with the Ku Band, you owe it to yourself to see how these latest developments from Microwave will bring you new concepts in receiver performance and crystal protection. Write or call our application engineering department.

MICROWAVE ASSOCIATES, INC.

BURLINGTON, MASS. TEL. BRowning 2-3000

SINGLE SIDE BAND FREQUENCY STANDARD

In flight for the U.S. Military
In production at James Knights



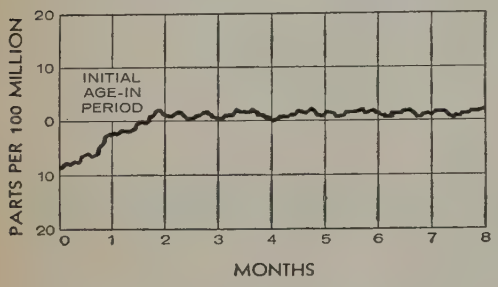
TIME PROVEN MODEL JKTO-P1A

Frequency Range: 1 to 5 mc
Stability: 1 x 10^{-7}/Day
Output: IV into 5,000 ohms
Power: Operates from 24 to 28V D.C.
Oven: Long life; booster and control thermostats hermetically sealed.
Dimensions: 1.8" x 2 x 3¼". Wt. 10 oz. max.

Environmental: Hermetically sealed; meets applicable aircraft equipment specifications with maximum frequency deviation of 4 x 10^{-7}.

Write for literature, stating your specific requirements.

LONG TERM STABILITY OF JKTO-P1A



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Common Stock
(Par Value 50c per Share)

Price $3.00 per share

Copies of the Offering Circular may be obtained from the undersigned only in those States in which the undersigned may legally offer these securities in compliance with the securities laws of the respective States.

ISSUER

AMERICAN TELEVISION & RADIO CO.
300 E. Fourth Street
St. Paul 1, Minnesota

June 1, 1959

NEWS New Products

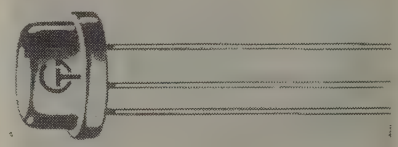
These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 192A)

available without charge from the **Electronic Engineering Co.,** 1601 E. Chestnut St., Santa Ana, Calif., developers of the ZA-100 System. The brochure details the ZA-100, which can solve 200 translation problems, end the punched card phase in computer/computer translations, and speed up conversions from one media to another. The brochure also shows typical commercial, industrial and scientific installations.

PNP Transistor

General Transistor Corp., 91-27 138th Place, Jamaica 35, N. Y., has announced a new high speed, high gain, silicon PNP alloy junction transistor to meet industrial and military needs for higher quality devices of this type. Now in pilot production, the unit will soon be commercially available in quantity.



Excellent switching and gain characteristics, coupled with low saturation resistance, are predicted for the device, which will be packaged in a TO-9 case.

Development of the unit has significance beyond its use in dc amplifiers and other linear applications, since it will make the use of silicon possible in such further applications as direct coupled and resistance coupled transistors and other extensions of transistor logic.

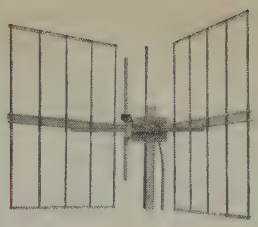
For complete technical specifications, write to firm.

Line Voltage Regulator

Longer life and better performance for electronic equipment are claimed with use of the new PoweRite broad band line voltage regulator introduced by **Armour Electronics,** 4201 Redwood Ave., Los Angeles 66, Calif.

These new, fully transistorized regulators provide 4 kva of power regulated to within ±0.5 per cent and operate equally

(Continued on page 197A)



ENLARGED VIEW OF ONE CORNER REFLECTOR ELEMENT

LONG RANGE REMOTE CONTROL

ANDREW engineers regularly solve difficult antenna problems. An example is the 32-element array recently designed for The Trans-Arabian Pipe Line Company for long range communication and control.

REQUIREMENT: A 160 mc antenna system for use at four unattended radio-controlled gas-turbine pumping units located 60 to 100 miles away from the main pump stations along 754 miles of pipeline. Minimum forward gain of 20 db over a dipole and maximum VSWR of 1.5 across 156-174 mc band were required. Existing towers dictated that the design feature minimum weight and wind loading together with maximum mechanical stability.

SOLUTION: ANDREW engineers specified, designed, and produced a rectangular array of 32 aluminum corner reflectors that met all electrical and mechanical requirements of this system for telemetry, control, and voice communication.

Installations like this demonstrate our ability to handle difficult antenna assignments. ANDREW engineers are ready to apply their know-how to your antenna system problems.

Andrew CORPORATION

363 EAST 75TH STREET • CHICAGO 19

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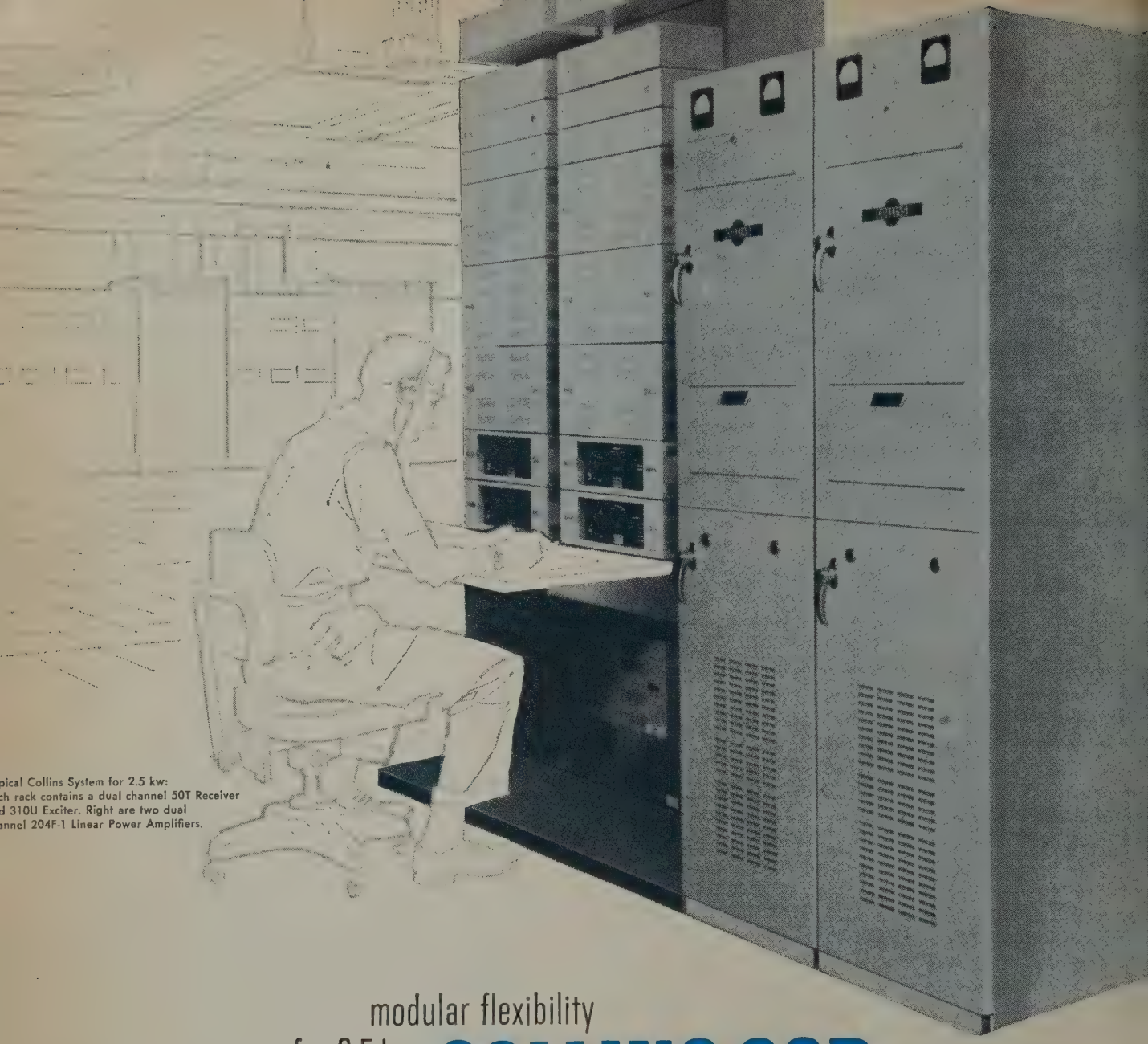
ANDREW

ANTENNAS • ANTENNA SYSTEMS • TRANSMISSION LINES



pical Collins System for 2.5 kw:
ch rack contains a dual channel 50T Receiver
d 310U Exciter. Right are two dual
annel 204F-1 Linear Power Amplifiers.

modular flexibility for 2.5 kw communication stations COLLINS SSB

The building block nature of the linear power amplifiers, exciters and receivers in Collins' single sideband line enables tailoring a system to the specific functions required or updating that system to expand these functions.

In the typical Collins system shown, the basic exciter is the 310U. This exciter uses plug-in modules as required to provide from 1 to 10 crystal-controlled channels in the 2 to 30 mc range. Exceptional circuit simplicity and reliability is achieved by a single conversion frequency generation scheme, with a crystal filter rejecting spurious products ahead of the RF amplifiers.

Although suitable for linear power amplifiers with higher output power, the 310U is employed in this illustration with the 2.5 kw PEP 204F-1 Linear Power Amplifier. This power amplifier has two sets of tuned circuits for rapid selection of either of two channels. Each channel is manually pretuned to any frequency in the 2 to 30 mc range.

Another 2.5 kw PEP linear power amplifier that might be employed is the 204H-1, which automatically senses the exciter signal frequency and tunes itself to that frequency.

Closely related to the 310U is the 50T Receiver. It has up to 10 channels in the 2 to 30 mc range, with single conversion and modular flexibility. A crystal filter ahead of the RF stages provides exceptional RF selectivity.

Other equipment in the complete Collins SSB line can provide from 100 watts to 45 kilowatts output with manual or automatic servo tuning. For more details, write for literature or contact a Collins representative.

COLLINS

COLLINS RADIO COMPANY • CEDAR RAPIDS, IOWA • DALLAS, TEXAS • BURBANK, CALIFORNIA

NEWS New Products

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 194A)

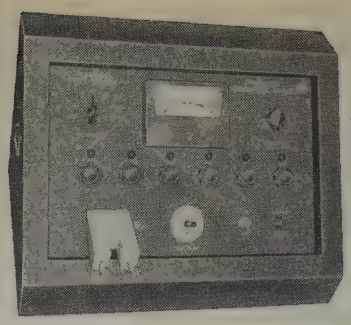
well at any frequency between 45 and 400 cps. They display response rates of better than 60 volts/second, are power factor insensitive and show less than 0.01 per cent total harmonic distortion.

Output is factory pre-set at 115 vac but can be varied with a screw driver adjustment between 110 and 120 vac. Standard units regulate to within 0.5 per cent over a range of +15 volts from the set point. Absolute protection against excess voltage under any circumstance is provided through automatic shutoff circuits available in two models—either manual or automatic reset.

The regulators are furnished in self contained cabinets for bench use or standard 19 inch rack mounted versions with $8\frac{3}{4}$ inch panel height. Prices start at $495.00, FOB Los Angeles. For further information, contact Armour.

"Go-No-Go" Bridge

A new concept in bridge design was recently announced by **General Resistance, Inc.**, 577 E. 156th St., New York 55, N. Y., offering ultra-high precision measurements at production speeds. The "Go-No-Go" Wheatstone Bridge makes possible the



measurement of resistors to 0.0035 per cent accuracy. This instrument has a sensitivity of 0.0005 per cent and has a 6-dial decade corresponding to 0.0005 per cent resolution, thus enabling the maximum utilization of both factors. It operates as a go-no-go limit bridge from 100 ohms to 11.111 meghoms with full scale tolerance selections of from 0.01 to 10 per cent and from one ohm to 111.11 megohms with full scale selections of 0.1 to 10 per cent. The bridge may also be used as a standard Wheatstone Bridge from one ohm to 111 megohms. Both the associated galvanometer and dc power supply are supplied internally. All controls are human-engineered for ease of operation.

Display Units

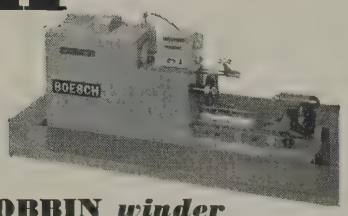
Several new features are offered in the latest In-Line Digital Display Unit manufactured by **Industrial Electronic Engineers, Inc.**, 3973 Lankershim Blvd., North Hollywood, Calif., producers of a complete

(Continued on page 198A)

BOESCH

BOESCH

★ *improved*
★ *faster*
★ *completely automatic*



BW2 BOBBIN *winder*

rugged, versatile, high speed winder for bobbins, solenoids, resistors, relays and other random-wound coils.

Boesch Manufacturing Co., Inc. Danbury, Conn.

HLAB

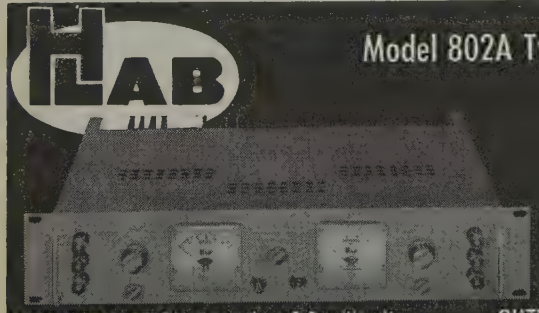
Model 802A Twin Transistorized Supply

EACH OUTPUT:

0-32 VOLTS

0-1.0 AMPERE

PRICE: $580.00



LINE REGULATION: Less than 3.0 millivolts
LOAD REGULATION: Less than 3.0 millivolts
RIPPLE AND NOISE: Less than 250 μv rms
SERIES CONNECTED: 0-64 Volts, 0-1.0 ampere

OUTPUT CONTINUOUSLY VARIABLE
REMOTE ERROR SENSING
AUTOMATIC OVERLOAD PROTECTION
CONVECTION COOLING: No moving parts

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. . . versatile
. . . low-priced

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- **Stable tuning head with 2 mc to 40 mc range with direct reading dial**
- **Two-tone generator with separate audio oscillators with independent frequency and amplitude controls. Output 2 volts max. per tone into 600 ohm load**
- **Internal calibrating and self checking circuitry**

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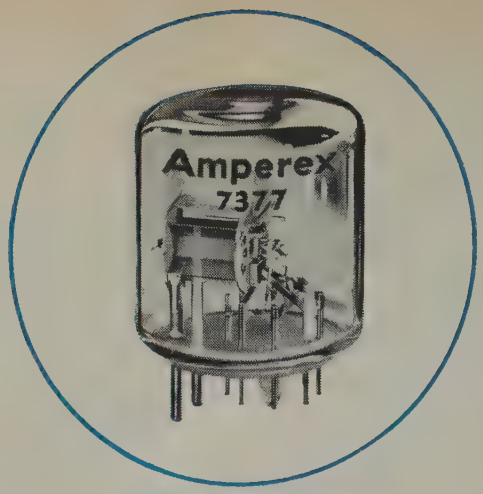

A TUBE WITH A FUTURE

THE NEW **Amperex®**
UHF TWIN-TETRODE
TYPE 7377

The need has long existed for stable tubes in the 500-1000 Mc. range. Now, with the availability of the Type 7377, the UHF equipment designer is provided with a uniquely constructed, uniquely efficient twin-tetrode capable of stable operation up to 1000 Mc.

THE UNIQUE CONSTRUCTION OF THE NEW AMPEREX TYPE 7377 . . .

● The plate lead structure and pins are isolated from the main socket, thereby making the anode pins an integral part of the external circuit. ● Plate lead structure, plus a tuning stub (which extends downwards through a cutout in the socket) permits exceptionally compact equipment packaging. ● Frame grid structure provides optimum reliability. ● Getter structure, and hence getter film, isolated from cage structure.

PLUS THE COMBINED EXCELLENCE OF THESE IMPRESSIVE FEATURES . . .

● Delivers 5.5 watts output (ICAS) at 960 Mc. ● Extremely low plate output impedance and capacitance. (Plate output cap: 0.82 $\mu\mu$f for both sections in push-pull operation.) ● Internally neutralized plate-to-grid capacitance (0.145 $\mu\mu$f for each section.) ● High transconductance (10,500 micromhos) ● High gain and high figure of merit.

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● Telemetering ● TV link communications ● Mobile and small transmitters ● Broadband amplifiers

TYPICAL OPERATION, CLASS C AMPLIFIER

	ICAS
Frequency	960 Mc/s
Plate Voltage	250 volts
Grid No. 2 Voltage	170 volts
Negative Grid No. 1 Voltage	15 volts
Plate Current	2 x 40 mA
Grid No. 2 Current	15 mA
Grid No. 1 Current	2 x 0.75 mA
Drive Power	1.4 watts
Plate Input Power	2 x 10 watts
Plate Dissipation	2 x 5.4 watts
Plate Power Output	8 watts
Load Power Output	5 watts

Amperex

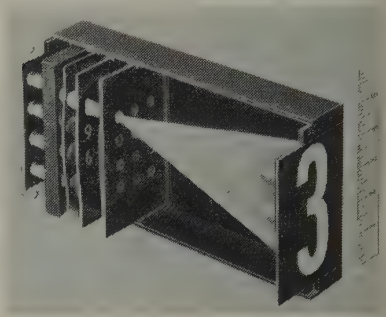
about tubes for RF, VHF, and UHF applications

AMPEREX ELECTRONIC CORPORATION
230 Duffy Avenue, Hicksville, Long Island, N.Y.
In Canada: Rogers Electronic Tubes & Components, 116 Vanderhoof Avenue, Toronto, Ontario

These manufacturers have invited PROCEEDINGS readers to write for literature and further technical information. Please mention your IRE affiliation.

(Continued from page 197A)

line of rear-projection-type readout displays.



This latest model is called the Series 80,000 In-Line Display and is approximately four times the size of the company's standard unit. It features three lenses (two condensing lenses plus one projection lens) to give a sharper, brighter digital presentation, states the manufacturer. With this optical system, the entire viewing screen is now illuminated.

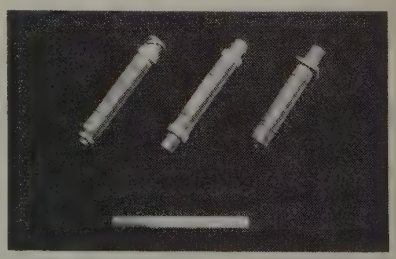
The size of the digit or character displayed is $3\frac{3}{4}$ high by 2 inches wide, and it can be viewed from over 100 feet away.

The body case is made of aluminum, and the overall size is $3\frac{1}{4}$ wide, $5\frac{1}{4}$ high, and $11\frac{1}{2}$ inches long. Individual units are priced at $33.00 each. Quantity prices are available upon request.

For more complete information write to the firm.

RF Filters

A new line of miniaturized low-pass RF filters, with cutoff frequencies from 0 to 1250 mc, is now available from **Telonic Industries, Inc.,** Beech Grove, Indiana.



The new filters provide sharp attenuation in the stop-band region. At a frequency of 1.2 times cutoff, the attenuation is 20 db or higher. At 1.5 times cutoff, it is at least 60 db. The result is a strong filtering action on the second harmonic of any frequency near cutoff, plus complete blanking of all higher harmonics.

A feature of the new lumped-constant filters is their small size. The overall length of filters down to 100 mc cutoff is $3\frac{1}{2}$ inches, including end connectors. This allows the units to be used in highly compact RF assemblies. An equivalent transmission-line type filter may measure 10 to 30 inches.

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MODEL MC-1

MAGNETIC CIRCUIT

The advanced Hall-effect device with *extreme linearity* and *low hysteresis* — simplifies a host of electronics operations for research and industry.

The Halltron Magnetic Circuit, Model MC-1, combines the new Halltron device with an efficient magnetic circuit. The result is a combination that realizes the full benefit of the device in many applications. The use of special magnetic materials and an indium arsenide Halltron results in extreme linearity and low hysteresis.

The MC-1 satisfies the requirements for such circuit applications as choppers, analog multipliers, power meters, modulators, phase detectors and many other electronic instruments. The magnetic circuit of the MC-1 is usable from DC through audio frequency range. The control current input to the Halltron may be operated into the megacycle range for chopper, modulator and similar service.

Two magnetic inputs for series or parallel operation are provided to achieve a wide range of impedances as well as circuit functions.

A low temperature coefficient of less than .1% per degree C is maintained over a wide temperature range. Coil impedances permit either 110 or 220 volt, 60 cycle operation. The unit is 1⅝″ wide (square base) and 2 5/16″ high. The casing is of mumetal to avoid interference.

Write for details and applications brochure.

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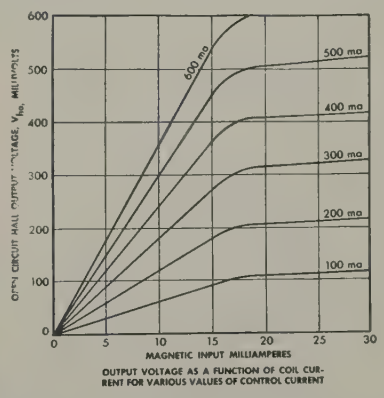
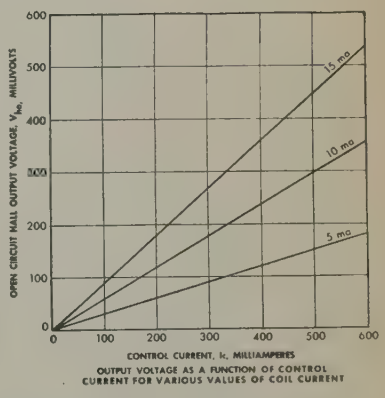
- Choppers (Modulators)
- Functions Generators
- Power Factor Indicators
- Impedance Matching Circuits
- Isolators

TYPICAL MC-1 CHARACTERISTICS



OUTPUT VOLTAGE AS A FUNCTION OF COIL CURRENT FOR VARIOUS VALUES OF CONTROL CURRENT



OUTPUT VOLTAGE AS A FUNCTION OF CONTROL CURRENT FOR VARIOUS VALUES OF COIL CURRENT

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IRE News and Radio Notes 14A
IRE People 48A
Industrial Engineering Notes 6A
Meetings with Exhibits 8A
Membership 158A
News—New Products 46A
Positions Open 130A
Positions Wanted by Armed Forces Veterans 124A
Professional Group Meetings 114A
Section Meetings 146A
Table of Contents 1A-2A

DISPLAY ADVERTISERS

A C Spark Plug Div., General Motors Corp. ..127A
ACF Industries, Inc., Erco Div. 170A
A.P.M. Corporation 116A
Abbott's Employment Specialists 161A
Accredited Personnel Service 166A
Aeronutronic Systems, Inc. 134A
Air-Marine Motors, Inc. 48A
Airborne Instruments Lab., Inc. 4A-5A
Aircraft Radio Corp. 146A
Airpax Electronics, Inc. 21A
Allen-Bradley Company 102A
American Television & Radio Co. 80A, 194A
American Time Products, Inc. 96A
Amperex Electronic Corp. 198A
Amperite Company, Inc. 10A
Ampex Corporation 105A
Amphenol Connector Div., Amphenol-Borg Electronics Corp. 118A
Andrew Corporation 195A
Ansley, Arthur C. 200A
Argonne National Lab. 149A
Armour Research Foundation, Illinois Institute of Technology 126A
Armstrong Whitworth Aircraft, Sir W. G. 90A

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Advertising Index

Arnold Engineering Co. 33A
Audio Development Co. 80A
Audio Devices, Inc. 203A
Augat Brothers, Inc. 188A
Automatic Metal Products Corp. 104A
Autonetics Div., North American Aviation, Inc. 181A
Avco Mfg. Corp., Crosley Div. 133A

Baird-Atomic, Inc. 184A
Ballantine Laboratories, Inc. 82A
Baracket, Albert J. 200A
Beckman & Whitley, Inc. 150A
Bell Telephone Laboratories 19A
Belleville-Hexem Corporation 190A
Bendix Aviation Corp., Bendix-Pacific Div. ... 136A
Bendix Aviation Corp., Bendix Products Div... 124A
Bendix Aviation Corp., Kansas City Div. 180A
Bendix Aviation Corp., Research Laboratories Div. 157A
Bendix Aviation Corp., York Div. 167A
Bickel, Richard L. 200A
Binswanger Associates, Charles A. 126A
Blaw-Knox Company 99A
Bliley Electric Company 186A
Boesch Mfg. Co., Inc. 197A
Bomac Laboratories, Inc. 17A
Buckbee Mears Company 192A
Burlingame Associates 54A
Burndy Corporation 190A
Burnell and Company, Inc. 23A
Bussmann Mfg. Div., McGraw Edison Co. ... 62A
Buttrick & Megary 182A

CBS Electronics, Semiconductor Operations ... 61A
Capitol Radio Engineering Institute 64A
Carad Corporation 52A
Carborundum Company 78A
Clevite Transistor Products 25A
Cohn Corporation, Sigmund 184A
Collins Radio Company 196A
Continental Device Corporation 31A
Convair Astronautics 153A
Cornell Aeronautical Lab., Inc. 167A
Cornell-Dubilier Electric Corp. ..... Cover 3
Corning Glass Works 95A

Dale Products, Inc. 63A
Daystrom Instrument Div. 132A
Delco Radio Div., General Motors Corp. 81A
DeMornay-Bonardi 121A
Dewey & Company, Inc., G. C. 134A
Donner Scientific Co. 162A

E H Research Laboratories 92A
ESC Corporation 57A
Ehrenfried, A. D. 200A
Eitel-McCullough, Inc. 79A
Electric Boat Div., General Dynamics Corp. 142A
Electro Instruments, Inc. 106A
Electronic Associates, Inc. 44A-45A
Electronic Research Associates, Inc. 8A
Empire Devices Products Corp. 123A
Erie Resistor Corporation 201A

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Freed Transformer Co., Inc. 72A

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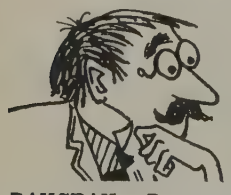

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Advertising Index

Gates Radio Company 161A
General Electric Company, Defense Systems Dept. 132A
General Electric Company, Heavy Military Electronics Dept. 183A
General Electric Company, Light Military Electronics Dept. 151A
General Mills, Inc. 165A
General Products Corporation 58A
General Radio Company ..... Cover 4
General Telephone Laboratories 160A
Gilfillan Brothers, Inc. 158A
Goodyear Aircraft Corporation 177A

Haller, Raymond & Brown, Inc. 183A
Hallicrafters Company 64A
Hallmark, Clyde E. 200A
Harrison Laboratories, Inc. 197A
Harvey-Wells Electronics, Inc. 76A
Heath Company 94A
Hewlett-Packard Company 11A, 108A-109A, 117A
High Voltage Engineering Corp. 150A
Hirschmann Co., Inc., Carl 72A
Huggins Laboratories 70A
Hughes Aircraft Company 128A-129A
Hughes Products, Industrial Systems and Controls Div. 77A
Hydro-Aire, Inc. 41A

Iliffe and Sons, Ltd. 83A
Institute of Radio Engineers 69A
International Business Machines Corp. 101A, 152A
International Telephone & Telegraph Corp., ... 86A-87A, 147A

Jet Propulsion Laboratory, Calif. Inst. of Techn., ... 155A
Johns Hopkins University, Applied Physics Lab. 98A
Johns Hopkins University, Operations Research Office 156A
Jones Div., Howard B., Cinch Mfg. Co. 112A
Jones Electronics Co., M. C. 116A

Kahn, Leonard R. 200A
Kay Electric Company 9A
Kearfott Company, Inc. 115A
Keithley Instruments, Inc. 120A
Kennedy & Company, D. S. 89A
Kepco Inc. 78A
Kinney Manufacturing Div., New York Air Brake Company 76A
Knights Company, James 194A
Kollsman Instrument Corp. 158A

Lambda Electronics Corp. 29A
Lapp Insulator Co., Inc. 114A
Librascope, Inc. 143A
Ling Electronics, Inc. 74A-75A
Link Aviation, Inc. 159A
Litton Industries, Inc., Electron Tube Div. 189A
Lockheed Aircraft Corp., California Div. 171A

Magnavox Company 161A
Magnetics, Inc. 71A
Mallory & Co., Inc., P. R. 119A
Martin Company, Orlando Div. 139A

Advertising Index

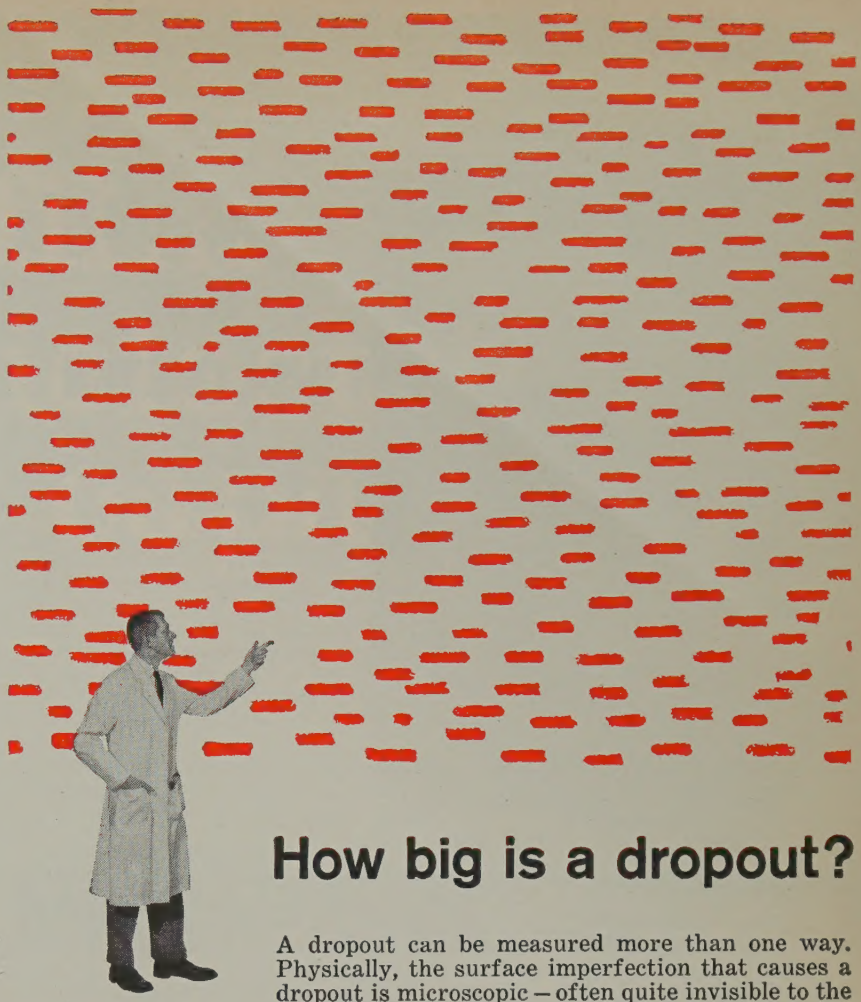
Massachusetts Institute of Technology, Instrumentation Lab. 148A
Massachusetts Institute of Technology, Lincoln Laboratory 138A
Matthews, J. A. and J. B. Minter 200A
Mayberry, Len 200A
Measurements, A McGraw Edison Div. 204A
Melpar, Inc. 179A
Microwave Associates, Inc. 193A
Millen Mfg. Co., Inc., James 6A
Moseley Company, F. L. 120A
Moskowitz, S. and D. D. Grieg 200A
Motorola, Inc., Western Military Electronics Center 140A
Mucon Corporation 92A

N. E. S., Inc. 141A
N J E Corporation 58A
N R C Equipment Corp. 122A
Narda Microwave Corp. 113A
National Aeronautics and Space Administration 151A
National Tel-Tronics Corp. 186A
New York University Press 84A
Nexon, V. J., S. K. Wolf and M. Westheimer 200A
North American Aviation, Inc. 138A, 157A, 171A, 181A
Northern Radio Co., Inc. 92A

Offner Electronics, Inc. 188A
Ohio Semiconductors, Inc. 199A
Ohmite Manufacturing Co. 91A
Olivetti Corporation 135A
Ordnance Research Laboratory, Pennsylvania State University 168A
Ostlund, E. M. 200A

Pan American World Airways, Inc. 154A
Panoramic Radio Products, Inc. 197A
Parke, Nathan Grier 200A
Perkin Engineering Corp. 104A
Permanent Employment Agency 177A
Phelps Dodge Copper Products Corp. 97A
Philco Corp., Govt. & Indl. Div. 111A
Philco Corp., Lansdale Tube Co. Div. 35A
Philco Corp., TechRep Div. 178A
Philco Corp., Western Dev. Labs. 137A
Polytechnic Research & Dev. Co., Inc. 103A
Price Electric Corp. 50A
Prodelin, Inc. 90A

Radio Corp. of America, Electron Tube Div. 100A
Radio Corp. of America, Missile & Surface Radar Dept. 164A
Radio Research Instrument Co. 190A
Raytheon Mfg. Co., Government Equipment Div. 131A
Raytheon Mfg. Co., Industrial Dept., Commercial Equip. Div. 202A
Raytheon Mfg. Co., Magnetic Components Products Dept. 60A
Raytheon Mfg. Co., Microwave and Power Tube Div. 47A
Raytheon Mfg. Co., Semiconductor Div. ..42A-43A
Reeves-Hoffman Div., Dynamics Corp. of America 122A
Republic Aviation Corp., ... 165A



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Advertising Index

Rixon Electronics, Inc. 192A
Rosenberg, Paul 200A
Royal McBee Corporation 49A

Sage Electronics Corp. 110A
Sanborn Company 185A
Sanders Associates, Inc. 164A
Scientific-Atlanta, Inc. 110A
Sensitive Research Instrument Corp. 104A
Servo Corporation of America 168A
Sola Electric Company 93A
Sorensen & Company, Inc. 56A
Southern Research Institute 136A
Specific Products 94A
Sperry Electronic Tube Div., Sperry Rand Corp. 141A
Sperry Gyroscope Co., Div. Sperry Rand Corp. 163A
Spittal, William R. 200A
Sprague Electric Company 3A, 7A, 59A
Stanford Research Institute 146A
Stavid Engineering, Inc. 130A
Stoddart Aircraft Radio Co., Inc. 76A
Stromberg-Carlson Company 27A, 82A, 177A
Superior Cable Corporation 88A
Sweet, C. M. 200A
Sylvania Electric Products Inc., Amherst Laboratory 174A
Sylvania Electric Products Inc., Data Systems Operations 172A
Sylvania Electric Products, Inc. Mountain View Operations 173A, 176A
Sylvania Electric Products Inc., Semiconductor Div. 12A-13A
Sylvania Electric Products Inc., Special Tube Operations 107A
Sylvania Electric Products Inc., Tube Division 65A-68A
Sylvania Electric Products Inc., Waltham Laboratories 175A

Technical Exchange Agency 179A
Technical Information Corp. 112A
Technical Materiel Corp. 72A
Tektronix, Inc. 73A
Texas Instruments, Incorporated 51A, 53A, 55A, 144A-145A
Times Facsimile Corporation 112A
Trancoa Chemical Corporation 39A

U. S. Naval Training Device Center 154A
U. S. Semiconductor Products, Inc. 70A
United Transformer Corporation ..... Cover 2
University of Arizona 180A

Waters Manufacturing, Inc. 37A
Western Gold & Platinum Co. 84A
Westinghouse Electric Corp., Baltimore Div. 125A, 169A
Westinghouse Electric Corp., Electronic Tube Div. 162A
Westinghouse Electric Corp., Semiconductor Dept. 187A
Weston Instruments, Div. Daystrom, Inc. 85A
Wheeler, Harold A. 200A
Winner, Lewis 200A

Yu, Y. P. 200A

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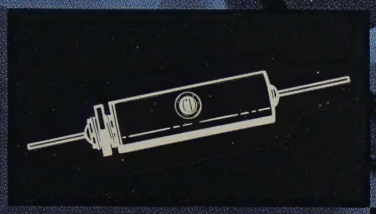

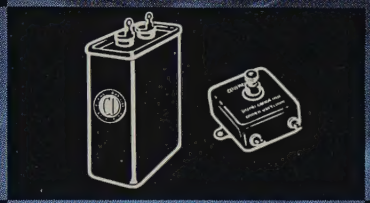

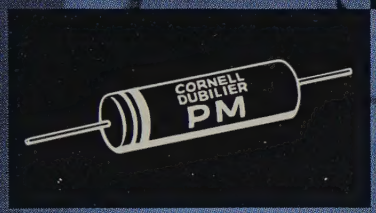

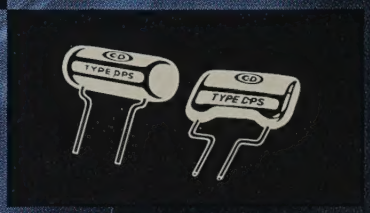

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